ALBERT-LUDWIGS-UNIVERSITÄT FREIBURG

Algorithms for Radio Networks

Routing, Flooding, DSR

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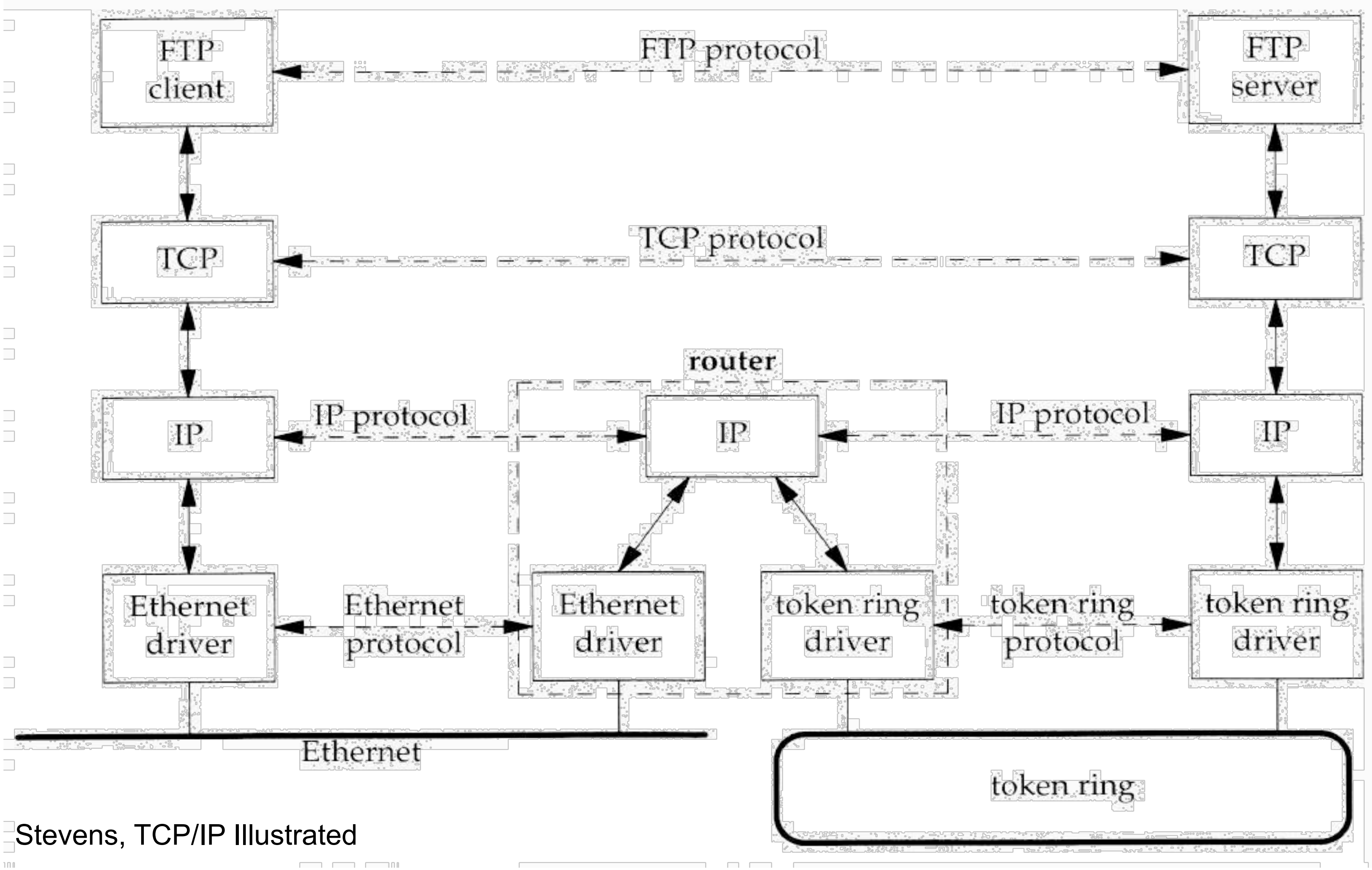
Protocols of the Internet

Application	Telnet, FTP, HTTP, SMTP (E-Mail), ...
Transport	TCP (Transmission Control Protocol) UDP (User Datagram Protocol)
Network	IP **(Internet Protocol)** + ICMP **(Internet Control Message Protocol)** + IGMP **(Internet Group Management Protocol)**
Host-to-Network	LAN **(e.g. Ethernet, Token Ring etc.)**

TCP/IP Layers

- **1. Host-to-Network**
  - Not specified, depends on the local network,k e.g. Ethernet, WLAN 802.11, PPP, DSL
- **2. Routing Layer/Network Layer (IP - Internet Protocol)**
  - Defined packet format and protocol
  - Routing
  - Forwarding
- **3. Transport Layer**
  - TCP (Transmission Control Protocol)
    - Reliable, connection-oriented transmission
    - Fragmentation, Flow Control, Multiplexing
  - UDP (User Datagram Protocol)
    - hands packets over to IP
    - unreliable, no flow control
- **4. Application Layer**
  - Services such as TELNET, FTP, SMTP, HTTP, NNTP (for DNS), ...

Example: Routing between LANs



Stevens, TCP/IP Illustrated

Routing Tables and Packet Forwarding

- **IP Routing Table**
  - contains for each destination the address of the next gateway
  - destination: host computer or sub-network
  - default gateway
- **Packet Forwarding**
  - IP packet (datagram) contains start IP address and destination IP address
    - if destination = my address then hand over to higher layer
    - if destination in routing table then forward packet to corresponding gateway
    - if destination IP subnet in routing table then forward packet to corresponding gateway
    - otherwise, use the default gateway

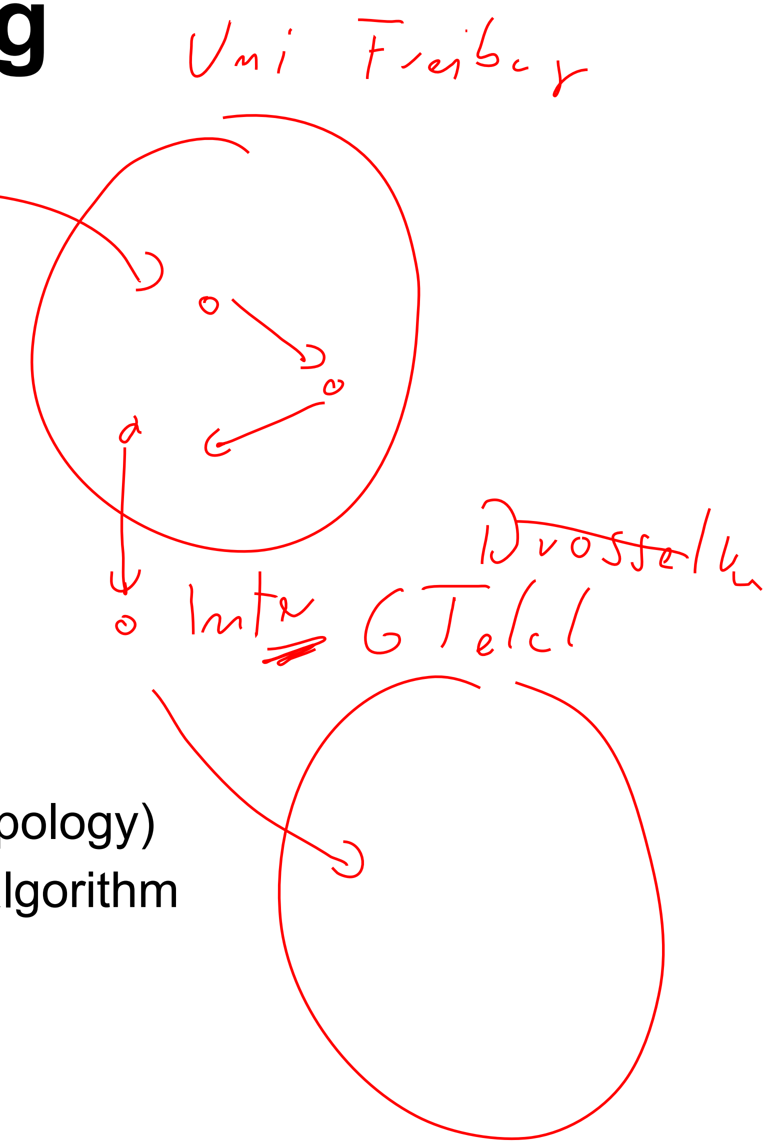
IP Packet Forwarding

- **IP -Packet (datagram) contains...**
  - TTL (Time-to-Live): Hop count limit
  - Start IP Address
  - Destination IP Address
- **Packet Handling**
  - Reduce TTL (Time to Live) by 1
  - If TTL ≠ 0 then forward packet according to routing table
  - If TTL = 0 or forwarding error (buffer full etc.):
    - delete packet
    - if packet is not an ICMP Packet then
      - send ICMP Packet with
        - start = current IP Address
        - destination = original start IP Address

Static and Dynamic Routing

- **Static Routing**
  - Routing table created manually
  - used in small LANs
- **Dynamic Routing**
  - Routing table created by Routing Algorithm
  - Centralized, e.g. Link State
    - Router knows the complete network topology
  - Decentralized, e.g. Distance Vector
    - Router knows gateways in its local neighborhood

Intra-AS Routing

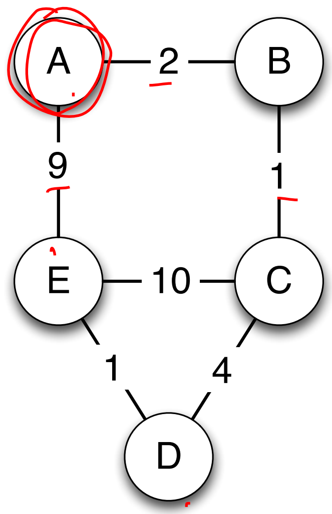


- **Routing Information Protocol (RIP)**
  - Distance Vector Algorithmus
  - Metric = hop count
  - exchange of distance vectors (by UDP)
- **Interior Gateway Routing Protocol (IGRP)**
  - successor of RIP
  - different routing metrics (delay, bandwidth)
- **Open Shortest Path First (OSPF)**
  - Link State Routing (every router knows the topology)
  - Route calculation by Dijkstra's shortest path algorithm

Distance Vector Routing Protocol

shortest path

- **Distance Table data structure**
  - Each node has a
    - Line for each possible destination
    - Column for any direct neighbors
- **Distributed algorithm**
  - each node communicates only with its neighbors
- **Asynchronous operation**
  - Nodes do not need to exchange information in each round
- **Self-terminating**
  - exchange unless no update is available



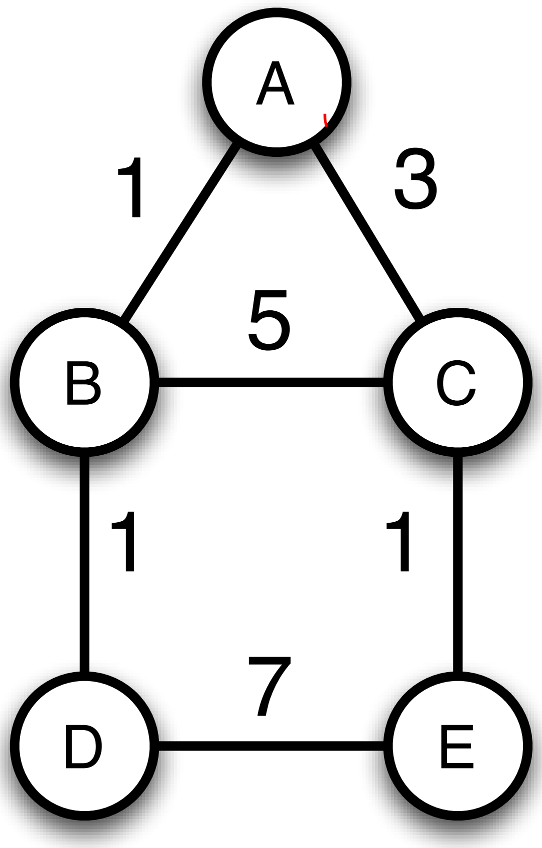
Distance Table for A

from A		via B	via E	Routing Table entry
to	B	**2**	15	B
	C	**3**	14	B
	D	**7**	10	B
	E	**8**	9	E

Distance Table for C

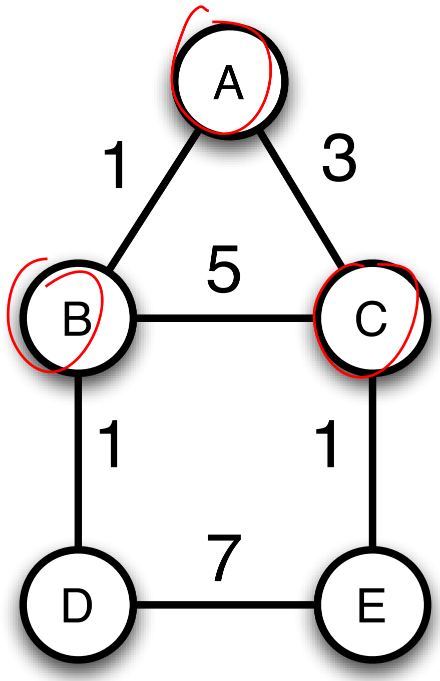
from C		via B	via D	via E	Routing Table entry
to	A	**3**	11	18	B
	B	**1**	9	21	B
	D	6	**4**	11	D
	E	7	**5**	10	D

Distance Vector Routing Example



from A to	via B	via C	entry
B	**1**	8	**B**
C	6	**3**	**C**
D	**2**	9	**B**
E	7	**4**	**C**

Distance Vector Routing



from A to	via		entry
	B	C	
B	1	∞ -	B
C	∞ -	3	C
D	-	-	-
E	-	-	-

from B to	via			entry
	A	C	D	
A	1	-	-	A
C	-	3	-	C
D	-	-	1	C
E	-	-	~~8~~	D

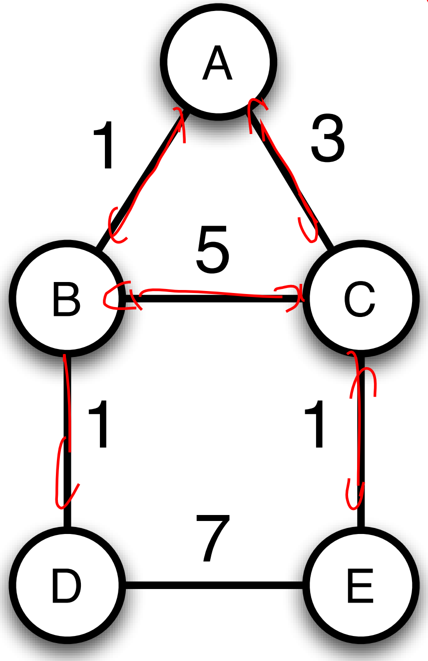
from C to	via			entry
	A	B	E	
A	3	-	-	A
B	-	5	-	B
D	-	-	8	E
E	-	-	1	E

Distance Vector Routing

from B to	via A	via C	via D	Entry
A	1	-	-	A
C	-	5	-	C
D	-	-	1	D
E	-	-	8	D

from C to	via A	via B	via E	Entry
A	3	-	-	A
B	-	5	-	B
D	-	-	8	E
E	-	-	1	E

from B to	via A	via C	via D	Entry
A	1	8	-	A
C	-	5	-	C
D	-	13	1	D
E	-	6	8	C

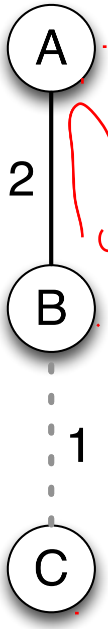


from C to	via A	via B	via E	Entry
A	3	6	-	A
B	-	5	-	B
D	-	6	8	B
E	-	13	1	E

“Count to Infinity” - Problem

- **Good news travels fast**
  - A new connection is quickly at hand
- **Bad news travels slowly**
  - Connection fails
  - Neighbors increase their distance mutally
  - "Count to Infinity" Problem

“Count to Infinity” - Problem



from A	via B	Routing Table entry
to B	2	B
to C	3	B

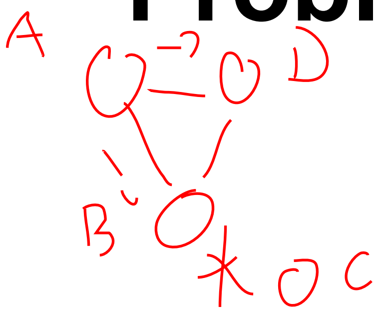
from B	via A	via C	Routing Table entry
to A	2	-	A
to C	5	-	A

from A	via B	Routing Table entry
to B	2	B
to C	7	B

from B	via A	via C	Routing Table entry
to A	2	-	A
to C	5	-	A

from A	via B	Routing Table entry
to B	2	B
to C	7	B

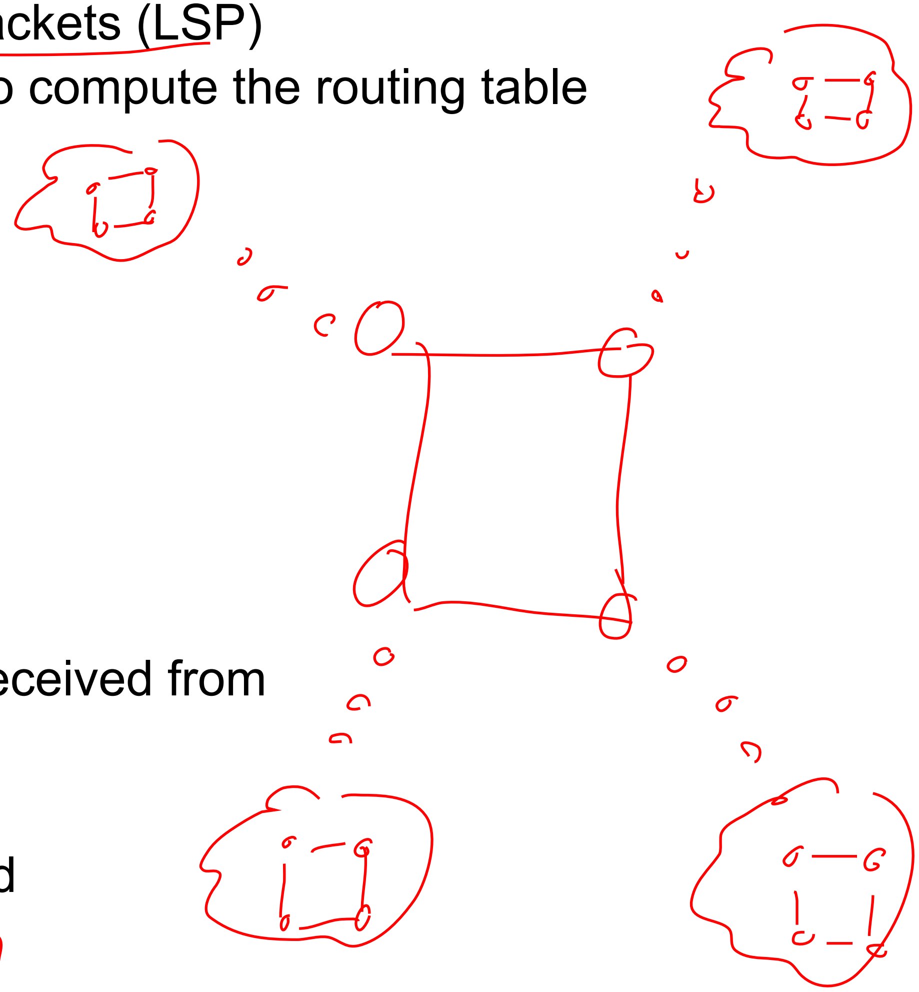
from B	via A	via C	Routing Table entry
to A	2	-	A
to C	9	-	A

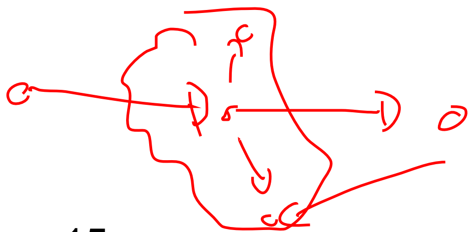


for B	via A	via C
to A	2	4
C	5	1

Link-State Protocol

- **Link state routers**
  - exchange information using Link State Packets (LSP)
  - each node uses shortest path algorithm to compute the routing table
- **LSP contains**
  - ID of the node generating the packet
  - Cost of this node to any direct neighbors
  - Sequence-no. (SEQNO)
  - TTL field for that field (time to live)
- **Reliable flooding (Reliable Flooding)**
  - current LSP of each node are stored
  - Forward of LSP to all neighbors
    - except to be node where it has been received from
  - Periodically creation of new LSPs
    - with increasing SEQNO
  - Decrement TTL when LSPs are forwarded





Characteristics of routing in mobile ad hoc networks

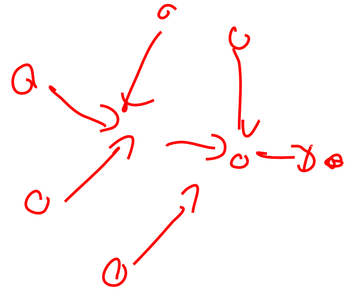
- **Movement of participants**
  - Reconnecting and loss of connection is more common than in other wireless networks
  - Especially at high speed
- **Other performance criteria**
  - Route stability in the face of mobility
  - energy consumption

Unicast Routing

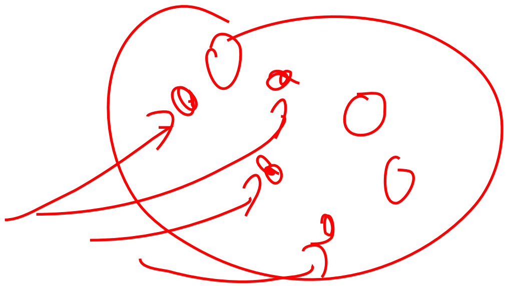
Point to Point

- **Variety of protocols**
  - Adaptations and new developments
- **No protocol dominates the other in all situations**
  - Solution: Adaptive protocols?

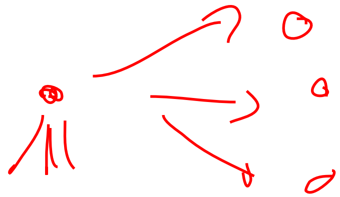
Convergecast



Multicast



Broadcast



all

Routing in MANETs

- **Routing**
  - Determination of message paths
  - Transport of data
- **Protocol types**
  - proactive
    - Routing tables with updates
  - reactive
    - repair~~m~~ of message paths only when necessary
  - hybrid
    - combination of proactive and reactive

Routing Protocols

- **Proactive**
  - Routes are **demand independent**
  - Standard Link-State und Distance-Vector Protocols
    - Destination Sequenced Distance Vector (**DSDV**)
    - Optimized Link State Routing (**OLSR**)
- **Reactive**
  - Route are determined when needed
    - Dynamic Source Routing (**DSR**)
    - Ad hoc On-demand Distance Vector (**AODV**)
    - Dynamic MANET On-demand Routing Protocol DYMO
    - Temporally Ordered Routing Algorithm (**TORA**)
- **Hybrid**
  - combination of reactive und proactive
    - Zone Routing Protocol (**ZRP**)
    - Greedy Perimeter Stateless Routing (**GPSR**)

many more

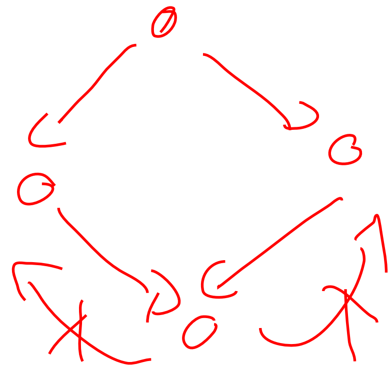
Source Route

Trade-Off

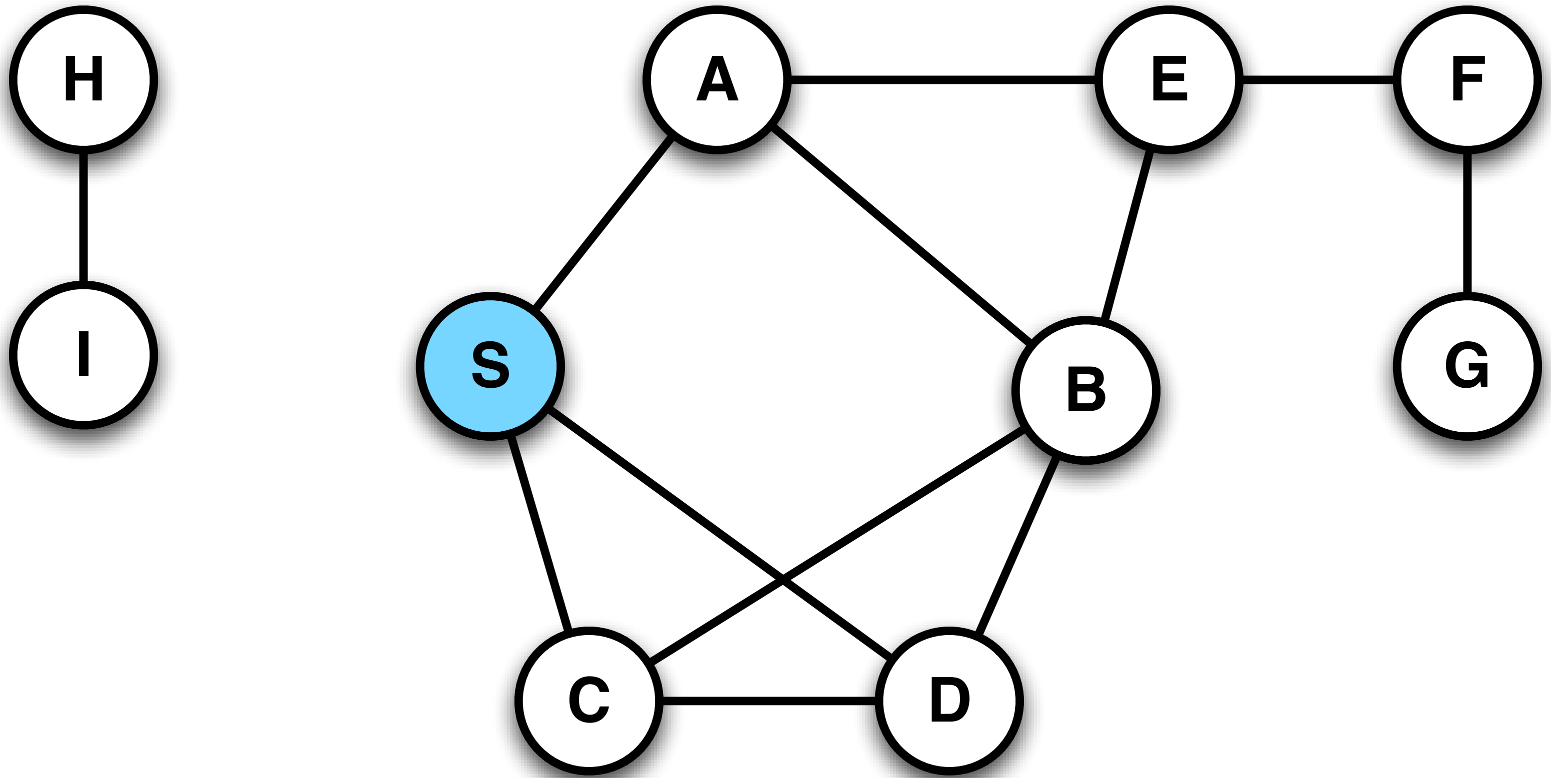
- **Laten~~z~~cy because of route discovery**
  - Proactive protocols are faster
  - Reactive protocols need to find routes
- **Overhead of Route discovery and maintenance**
  - Reactive protocols have smaller overhead (number of messages)
  - Proactive protocols may have larger complexity
- **Traffic-Pattern and mobility**
  - decides which type of protocol is more efficient

Flooding

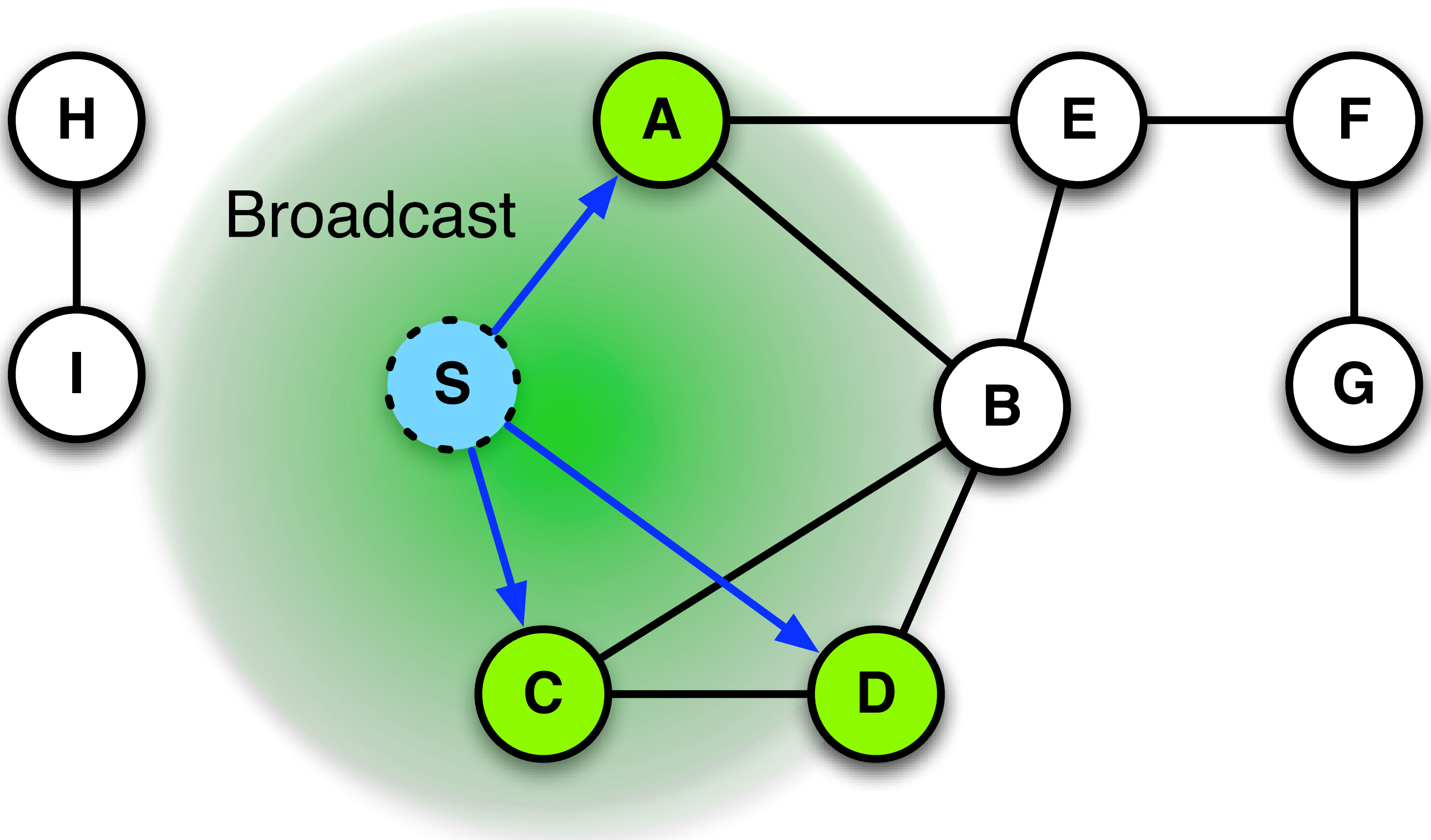
- **Algorithm**
  - Sender S broadcasts data packet to all neighbors
  - Each node receiving a new packet
    - broadcasts this packet
    - if it is not the receiver
- **Sequence numbers**
  - identifies messages to prevent duplicates
- **Packet always reaches the target**
  - if possible



Flooding Example

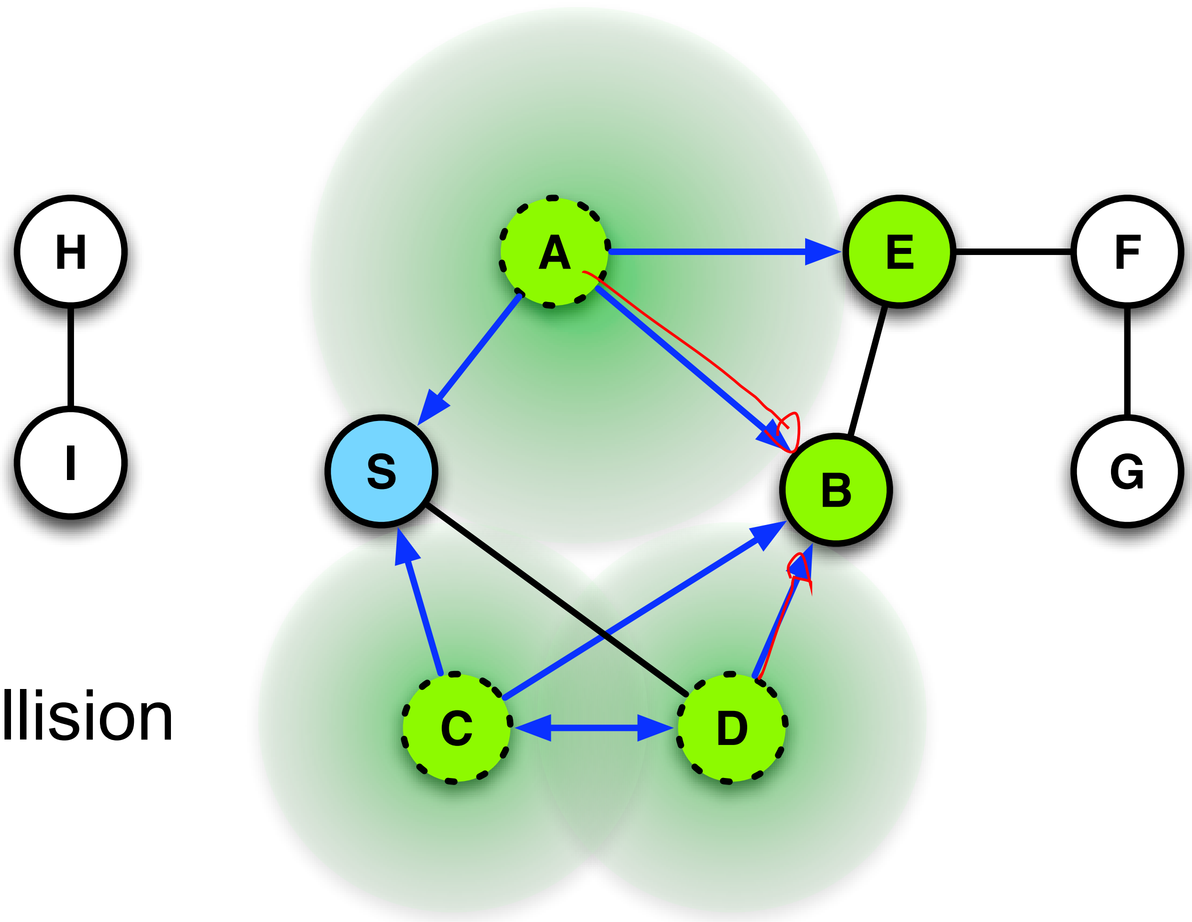


Flooding for Data Delivery



Packet for Receiver F

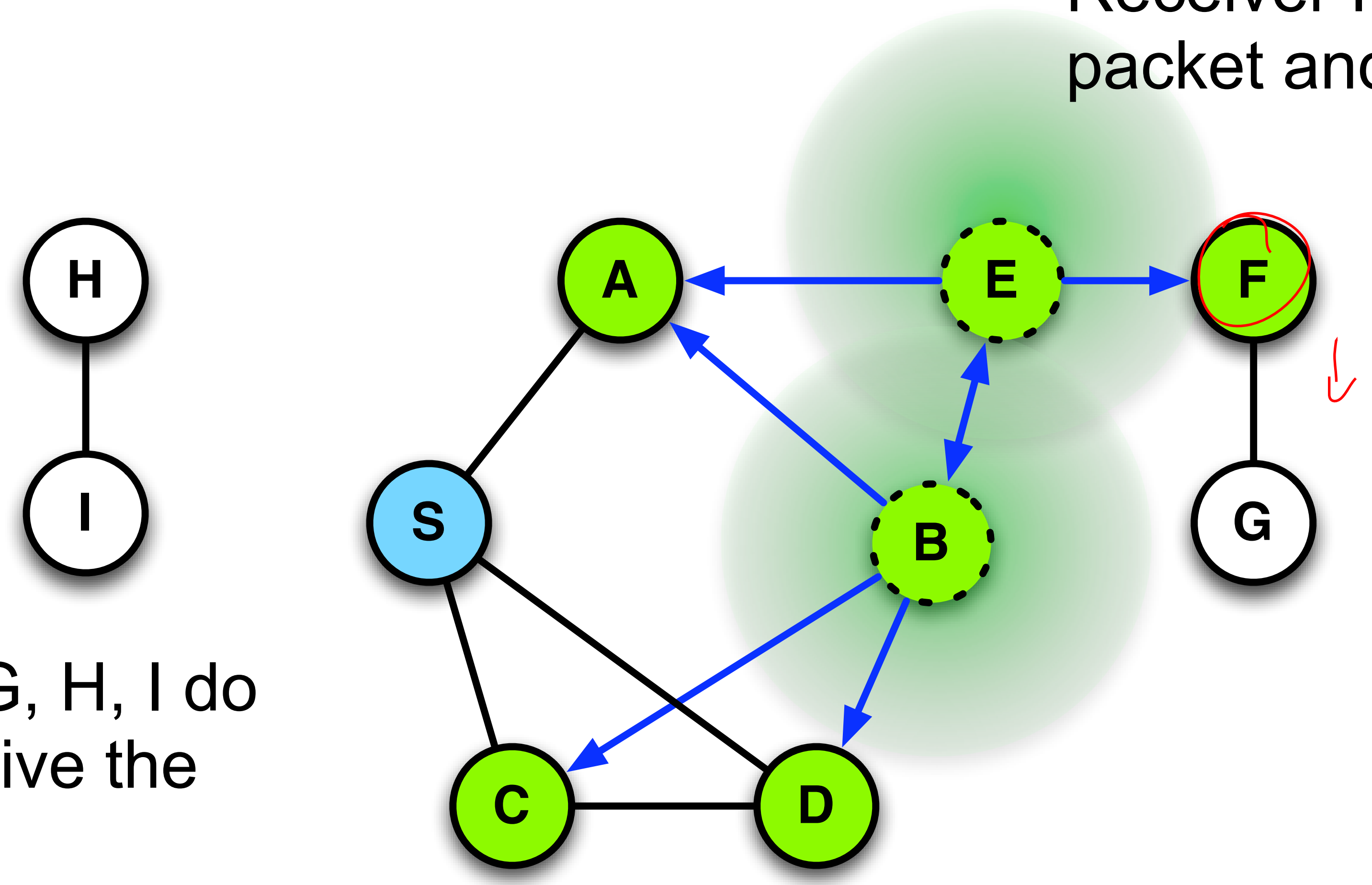
Flooding for Data Delivery



Possible collision at B

Flooding for Data Delivery

Receiver F gets packet and stops



Nodes G, H, I do not receive the packet

Flooding

- **Advantage**
  - simple and robust
  - the best approach for short packet lengths, small number of participants in highly mobile networks with light traffic
- **Disadvantage**
  - High overhead
  - Broadcasting is unreliable
    - lack of acknowledgements
    - hidden, exposed terminals lead to data loss or delay

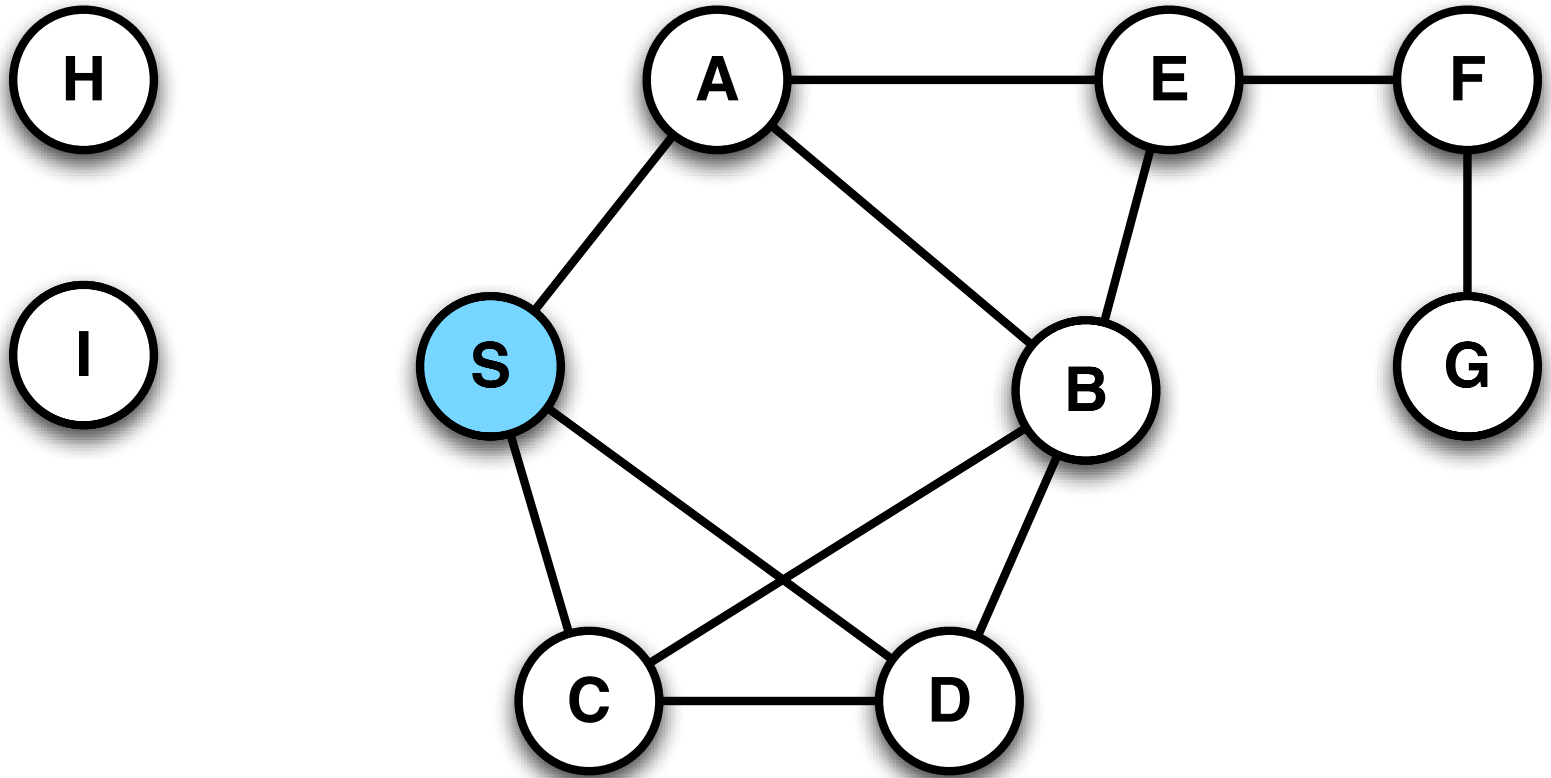
Flooding

- **Produces too many unnecessary (long) data packets**
  - in the worst case, each participant sends each packet
  - many long transmissions collisions lead to long waiting times in the medium access
- **Better approach:**
  - Use of control packets for route determination
  - Flooding of control packet leads to DSR

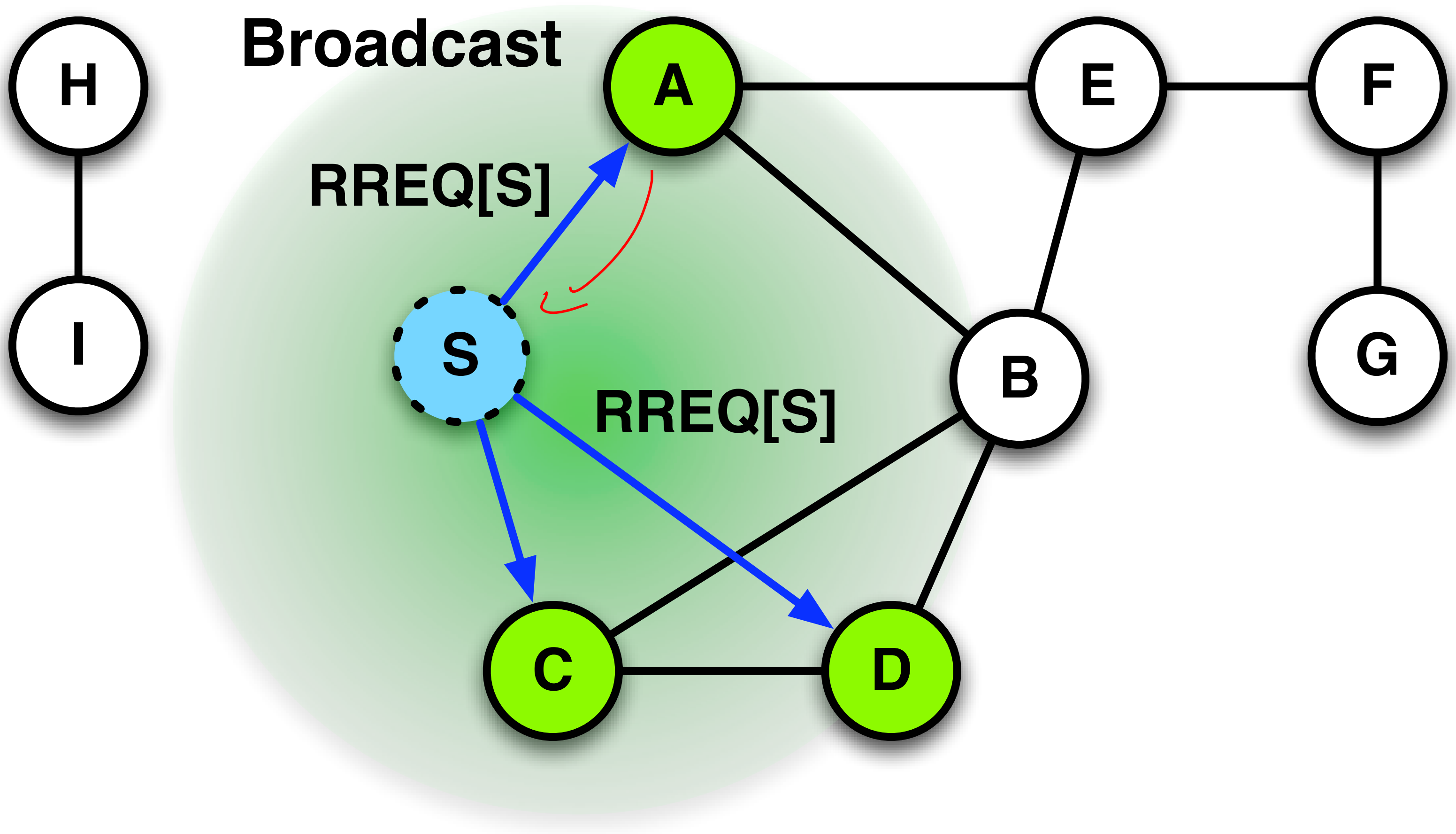
Dynamic Source Routing (DSR)

- **Johnson, Maltz**
  - *Dynamic Source Routing in Ad Hoc Wireless Networks*, Mobile Computing, 1996
- **Algorithm**
  - Sender initiates route discovery by flooding of **Route-Request (RREQ)**-packets
    - Each forwarding node appends his ID to the RREQ-packet
  - The receiver generates the routing information from the RREQ packet by producing a **Route-Reply (RREP)-**packet
    - using the route information of the packet is sent back to the sender
  - Transmitter sends **data packet** along with route information to the receiver

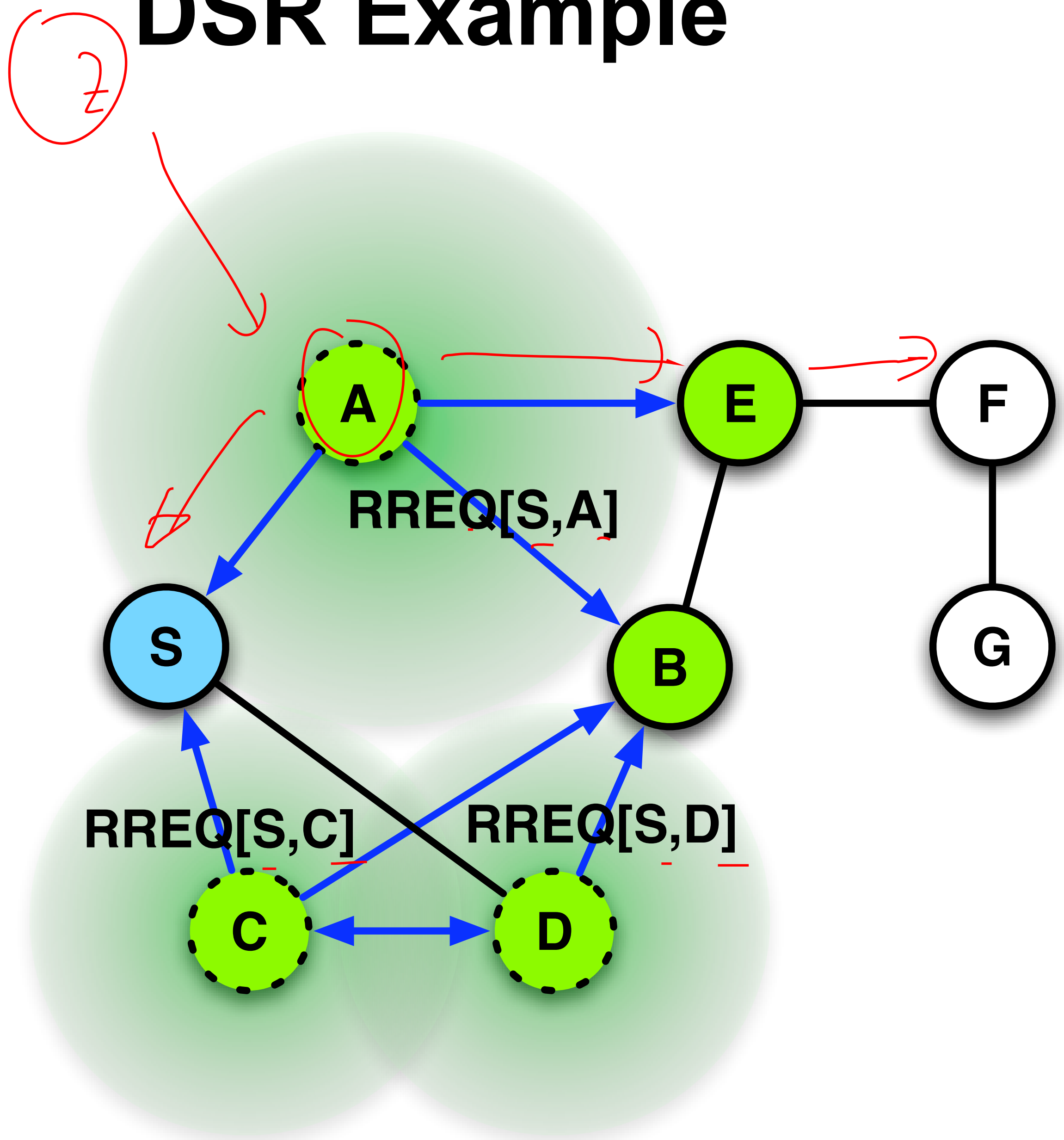
DSR Example



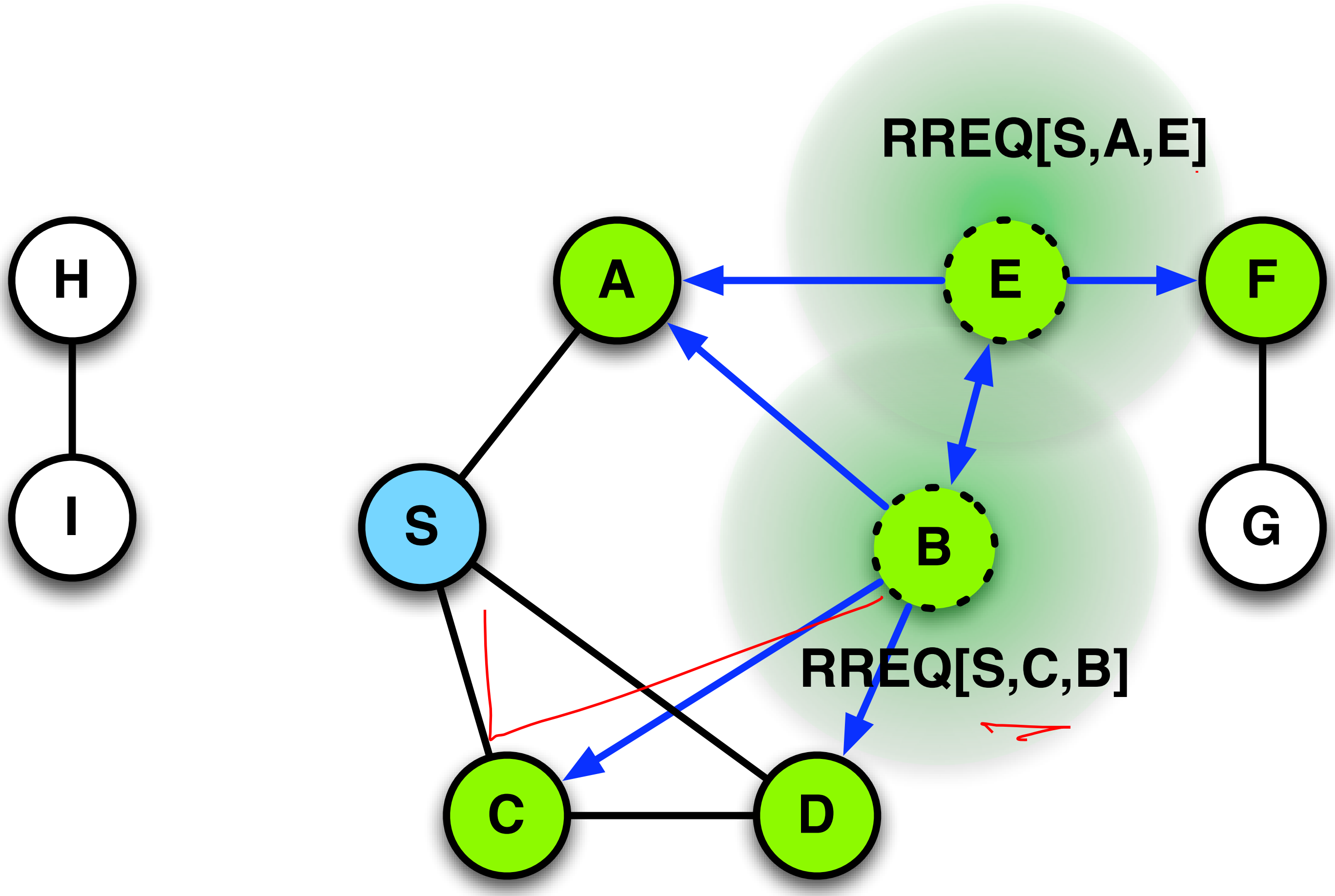
DSR Example



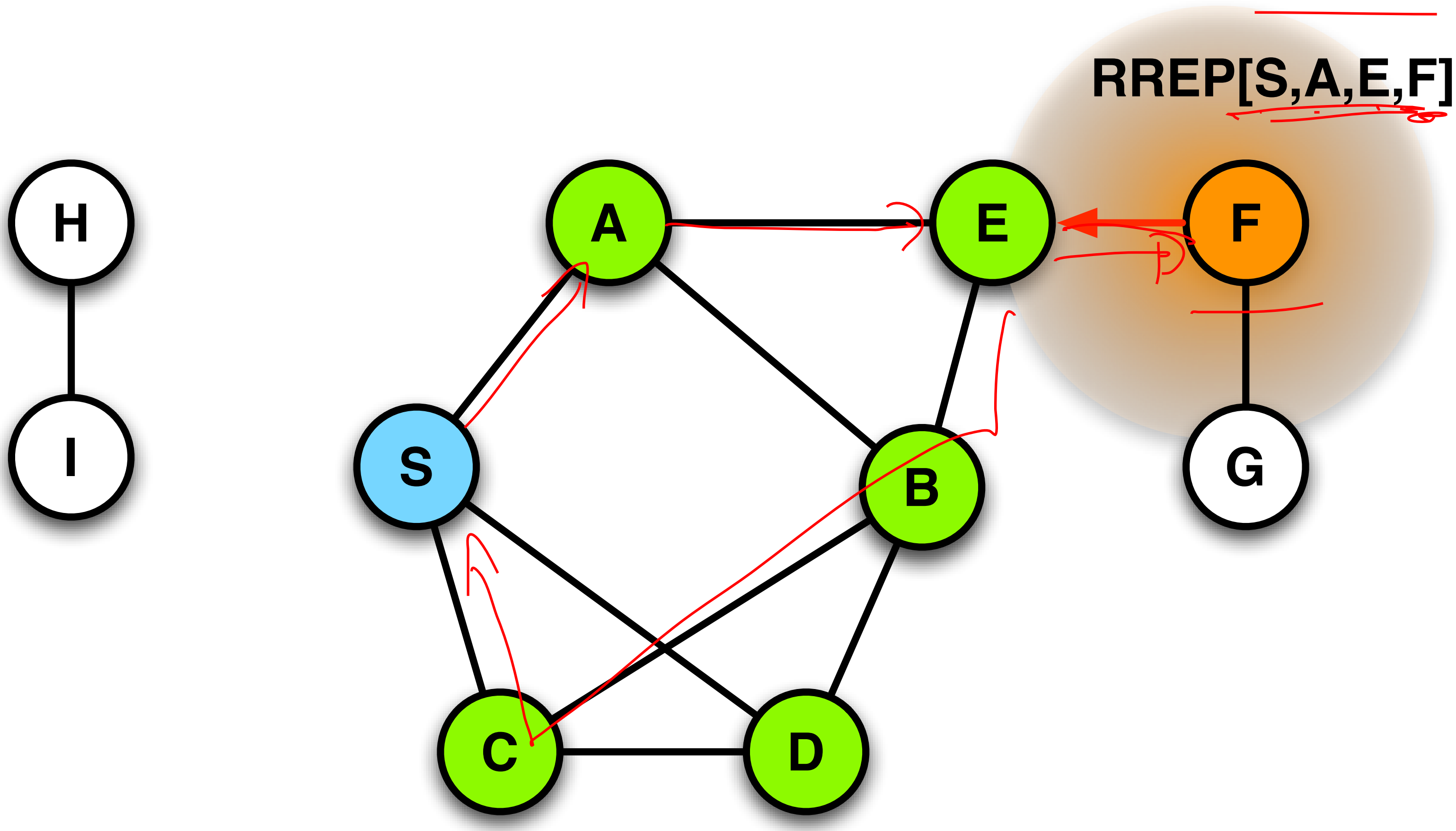
DSR Example



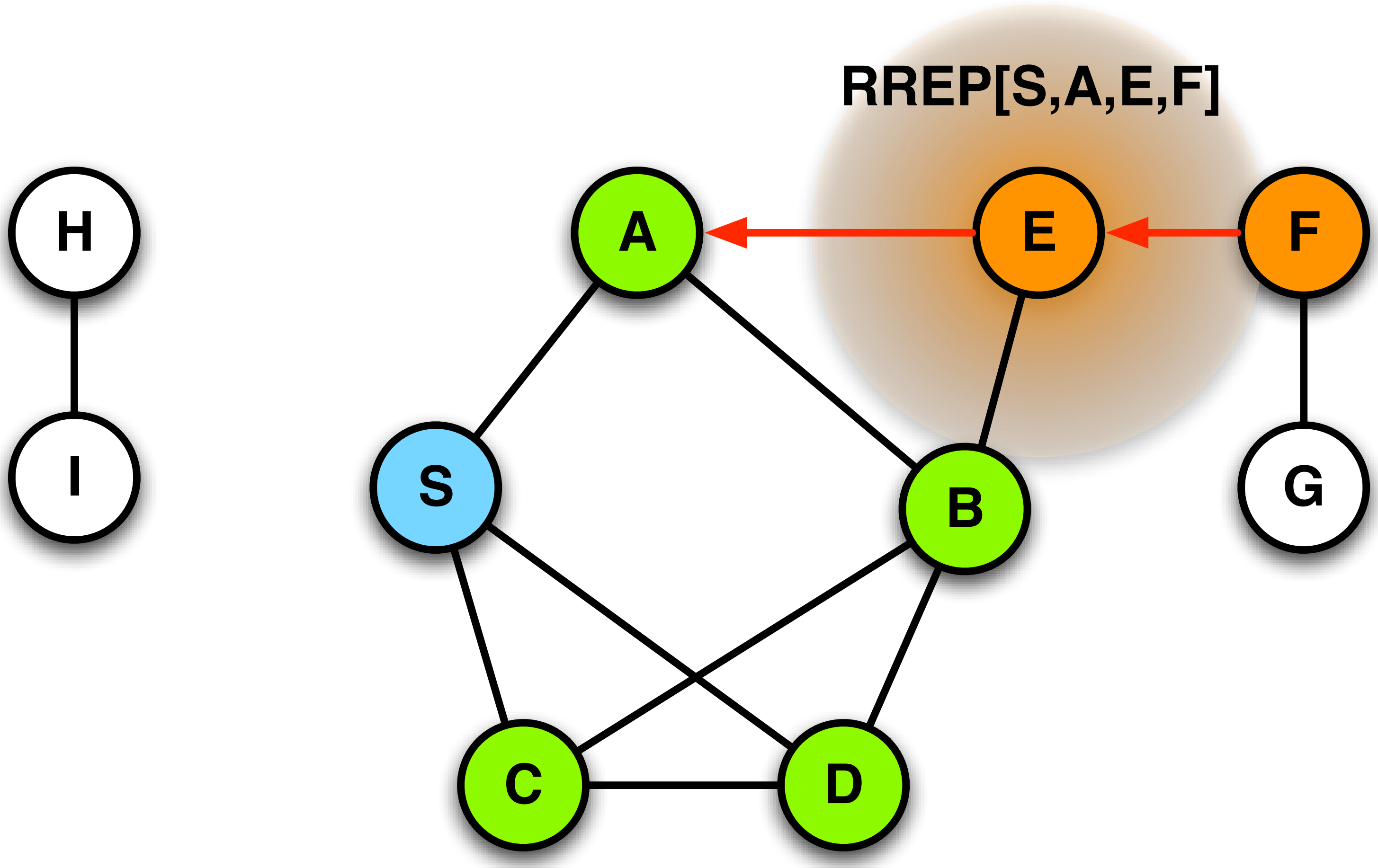
DSR Example



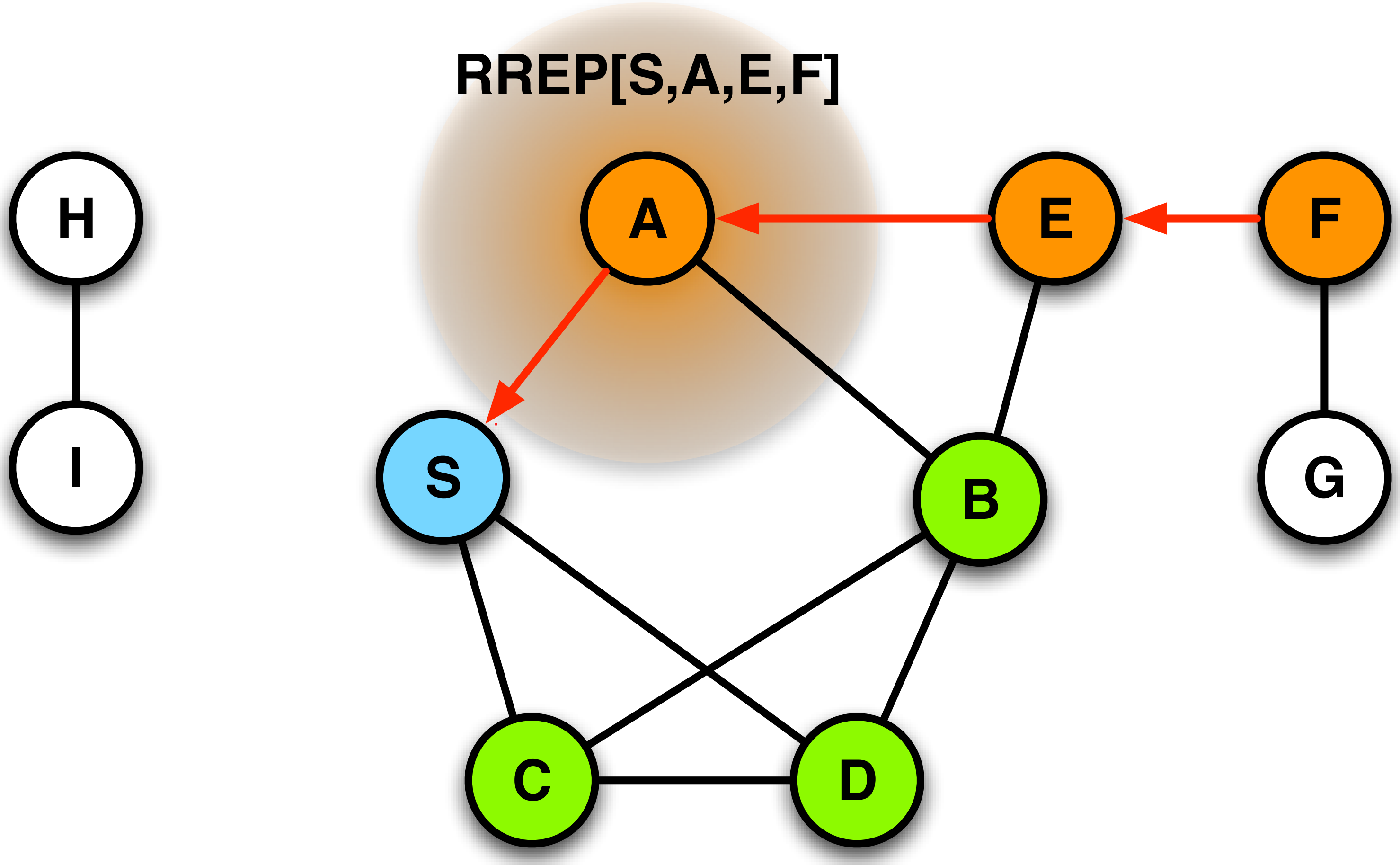
DSR Example



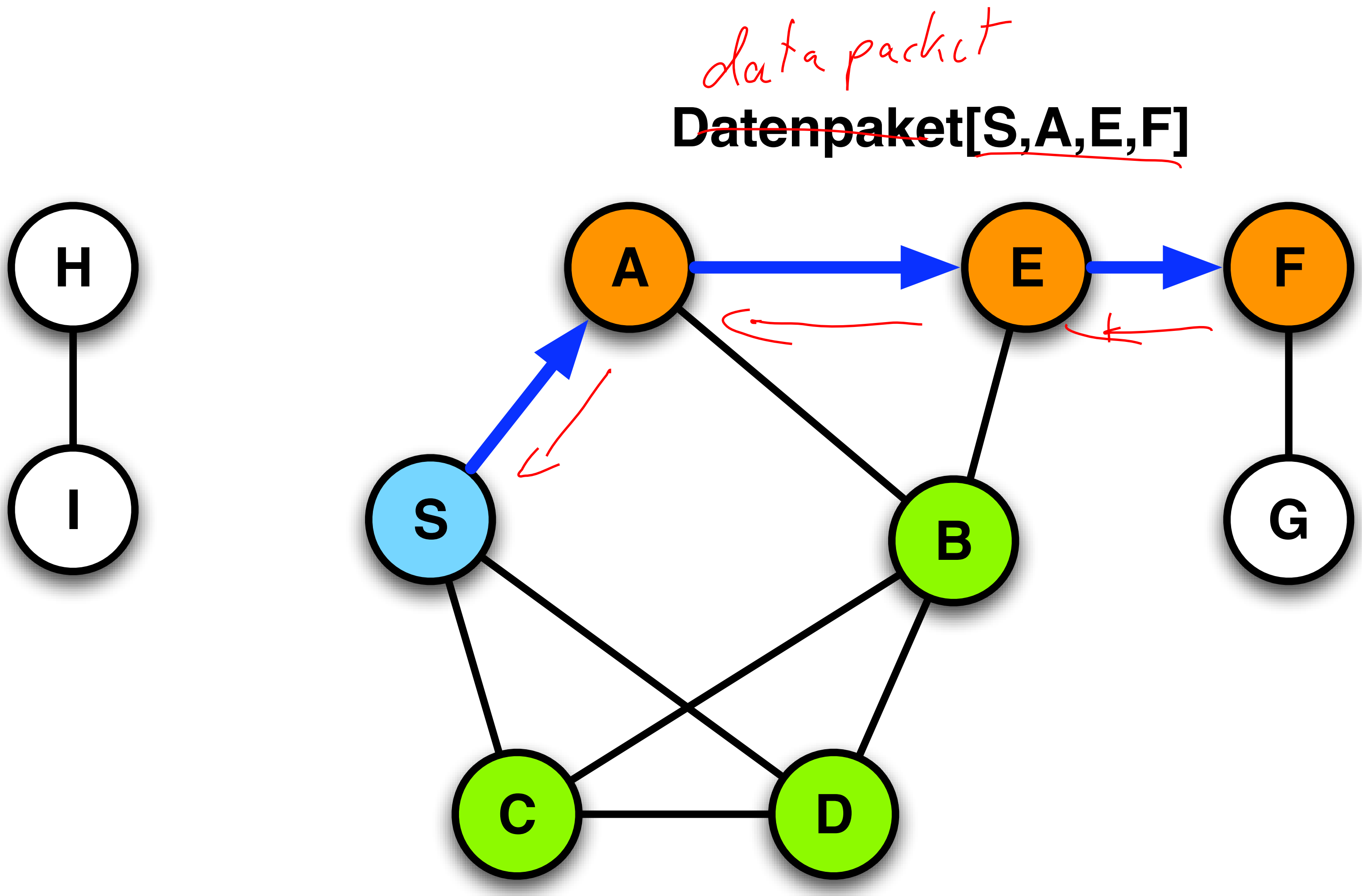
DSR Example



DSR Example



DSR Example



Requirements

- **Route Reply**
  - requires bidirectional connections
  - unidirectional links
    - must be tested for symmetry
    - or Route-Reply must trigger its own route-request
- **Data packet has all the routing information in the header**
  - hence: Source-Routing
- **Route determination**
  - if no valid route is known

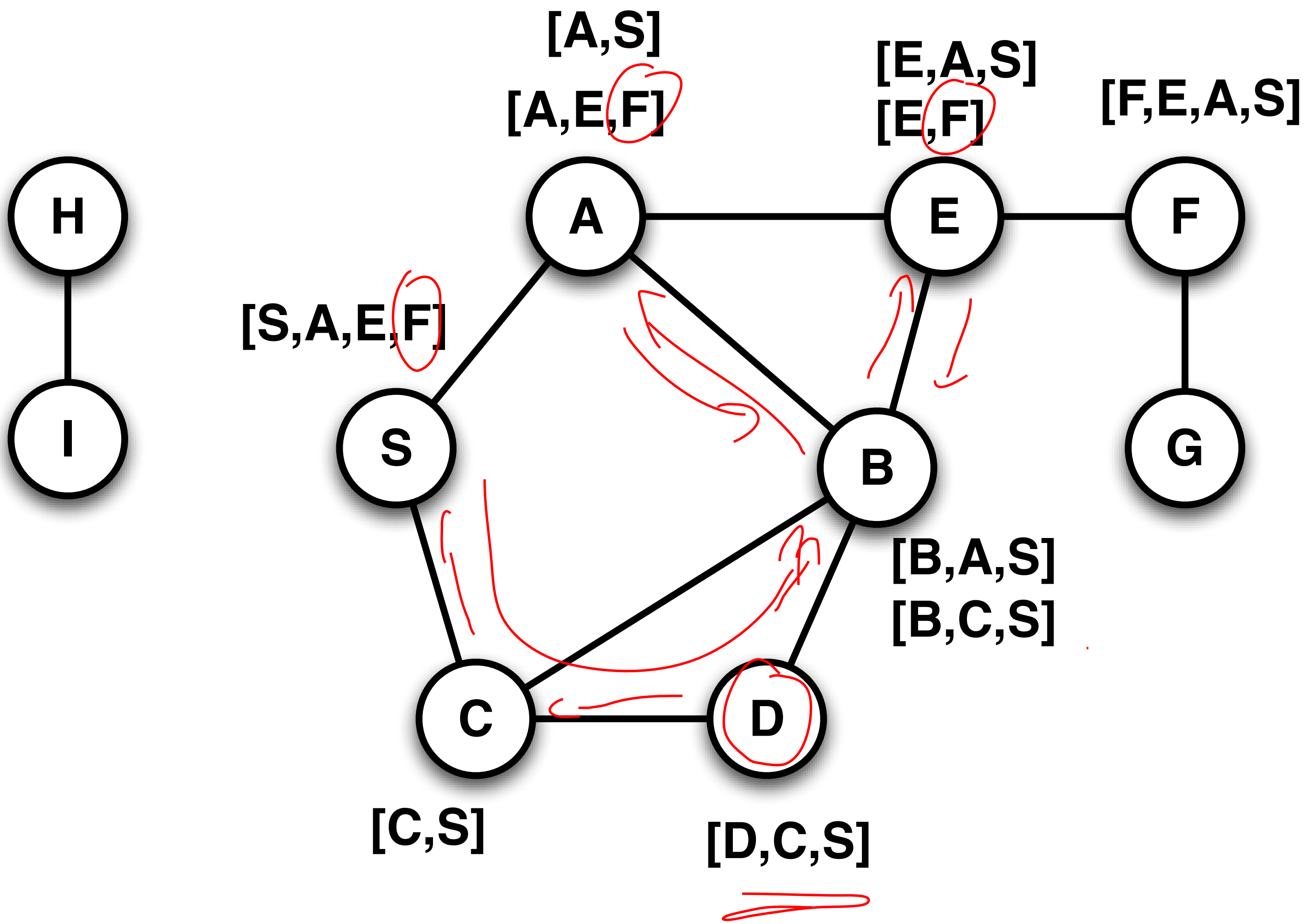
DSR Extensions and Modifications

- **Intermediate nodes can cache information RREP**
  - Problem: stale information
- **Listening to control messages**
  - can help to identify the topology
- **Random delays for answers**
  - To prevent many RREP-packets (Reply-Storm)
  - if many nodes know the answer (not for media access)
- **Repair**
  - If an error is detected then usually: route recalculation
  - Instead: a local change of the source route
- **Cache Management**
  - Mechanisms for the deletion of outdated cache information

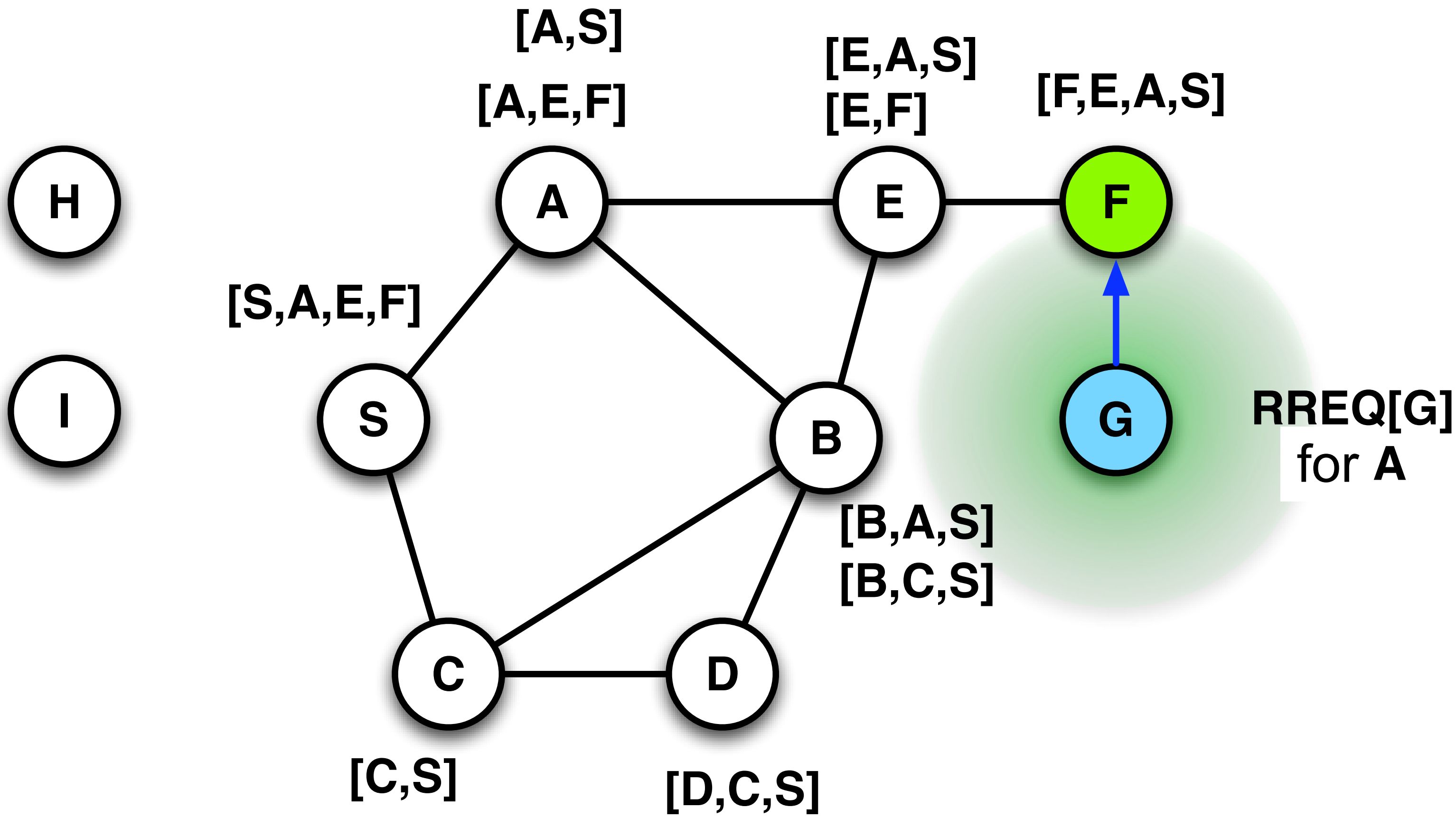
DSR Optimization Route Caching

- **Each node stores information from all available**
  - Header of data packets
  - Route Request
  - Route-Reply
  - partial paths
- **From this information, a route reply is generated**

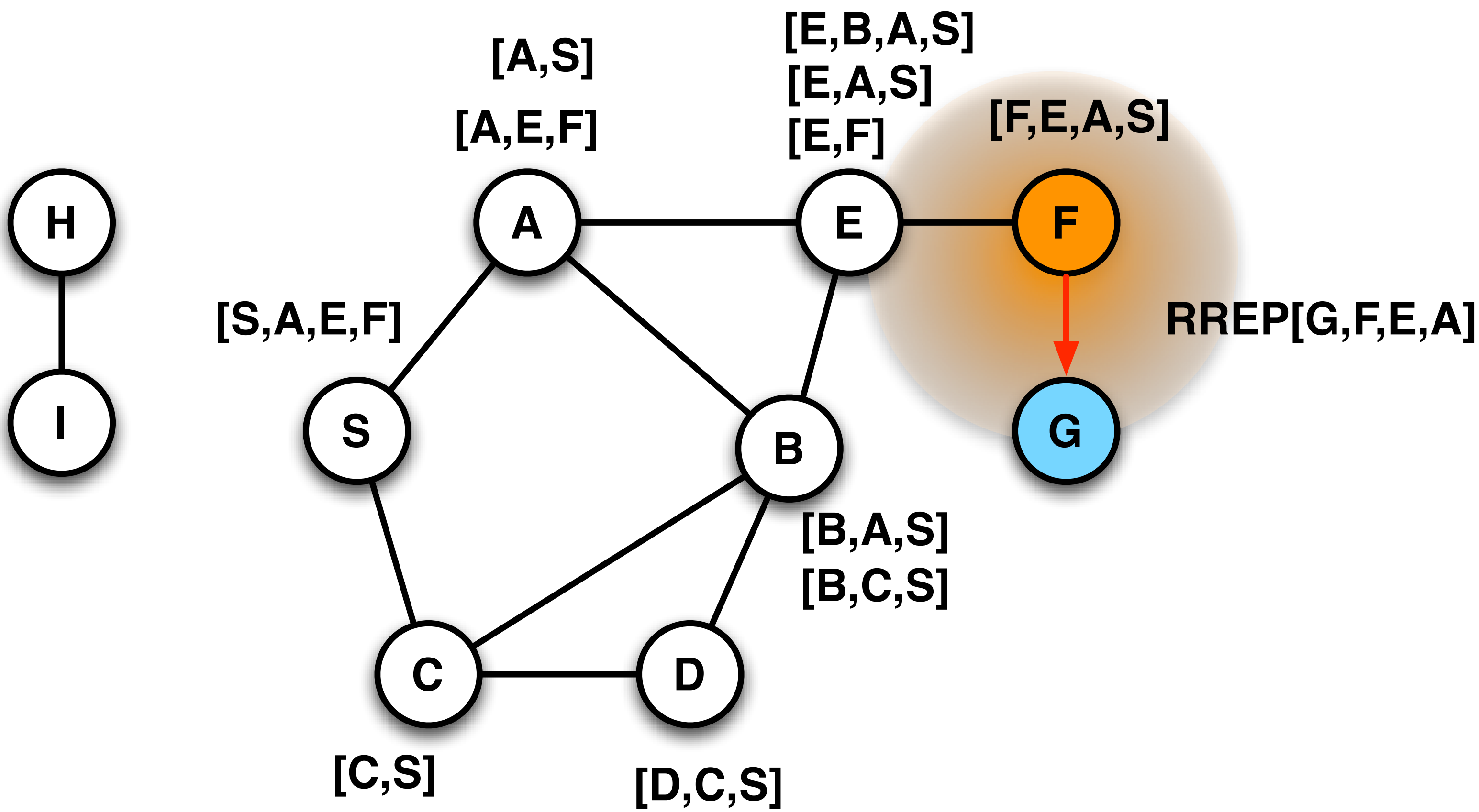
DSR Route Caching



DSR Route Caching

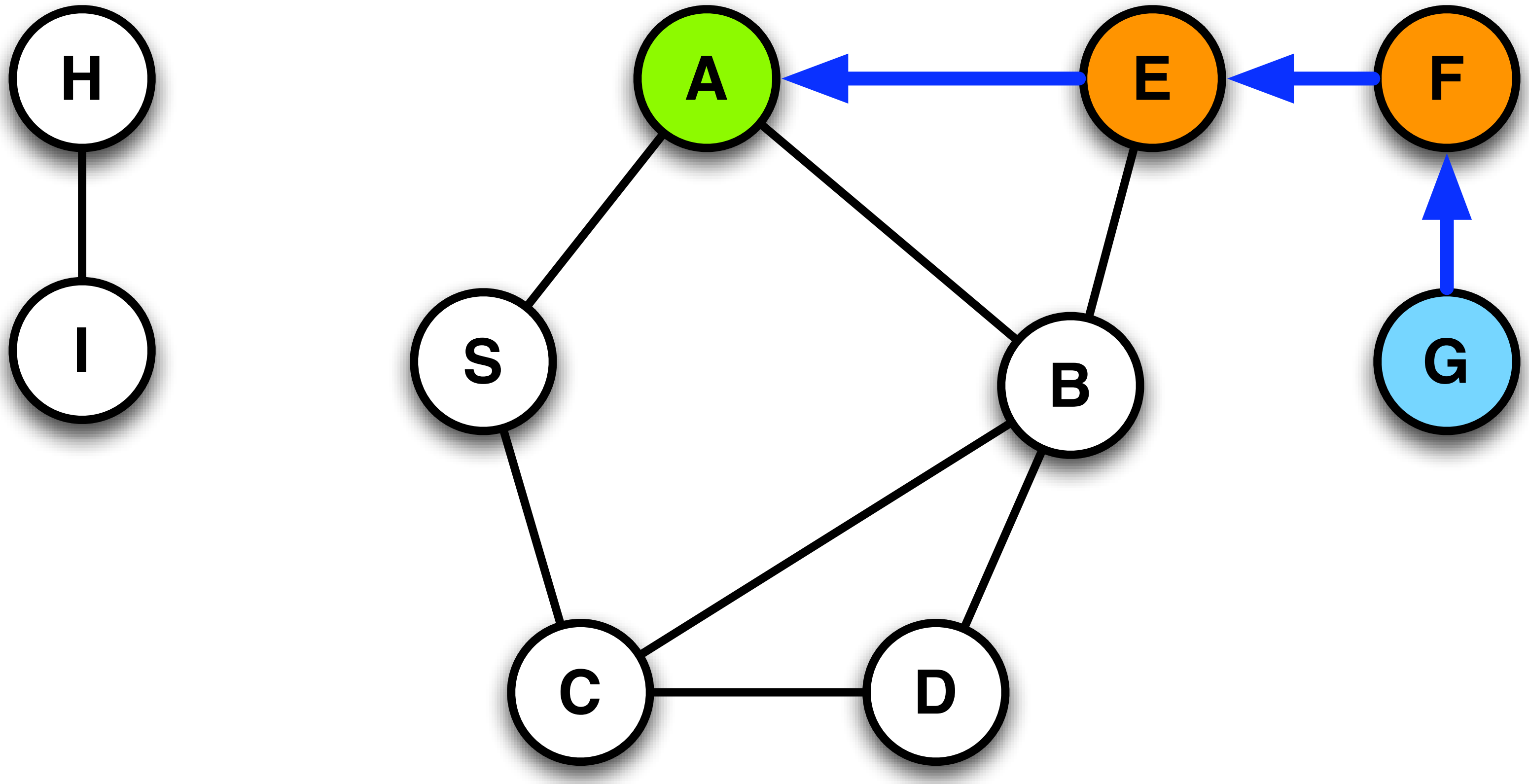


DSR Route Caching



DSR Route Caching

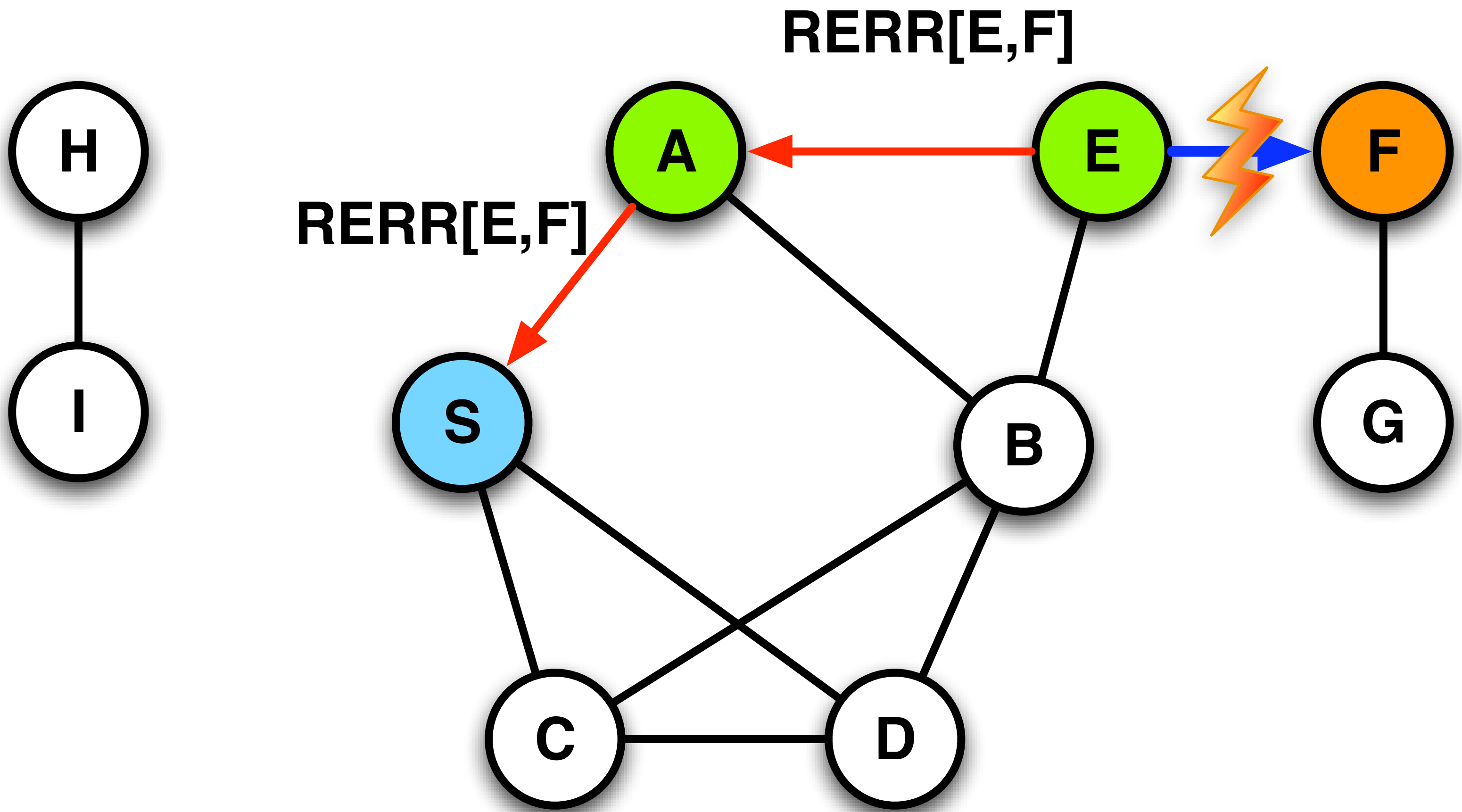
Data packet [G,F,E,A]



DSR Optimization
Route Caching

- **If any information is incorrect**
  - because a route no longer exists
  - then this path is deleted from the cache
  - alternative paths are used
  - or RREQ is generated
- **Missing links are distributed by (RERR) packets in the network**

Route Error



DSR Discussion

- **Benefits**
  - Routes are maintained only between communicating nodes
  - Route caching reduces route search
  - Caches help many alternative routes to find
- **Disadvantages**
  - Header size grows with distance
  - Network may be flooded with route requests
  - Route-Reply-Storm
  - Outdated information may cause cache overhead

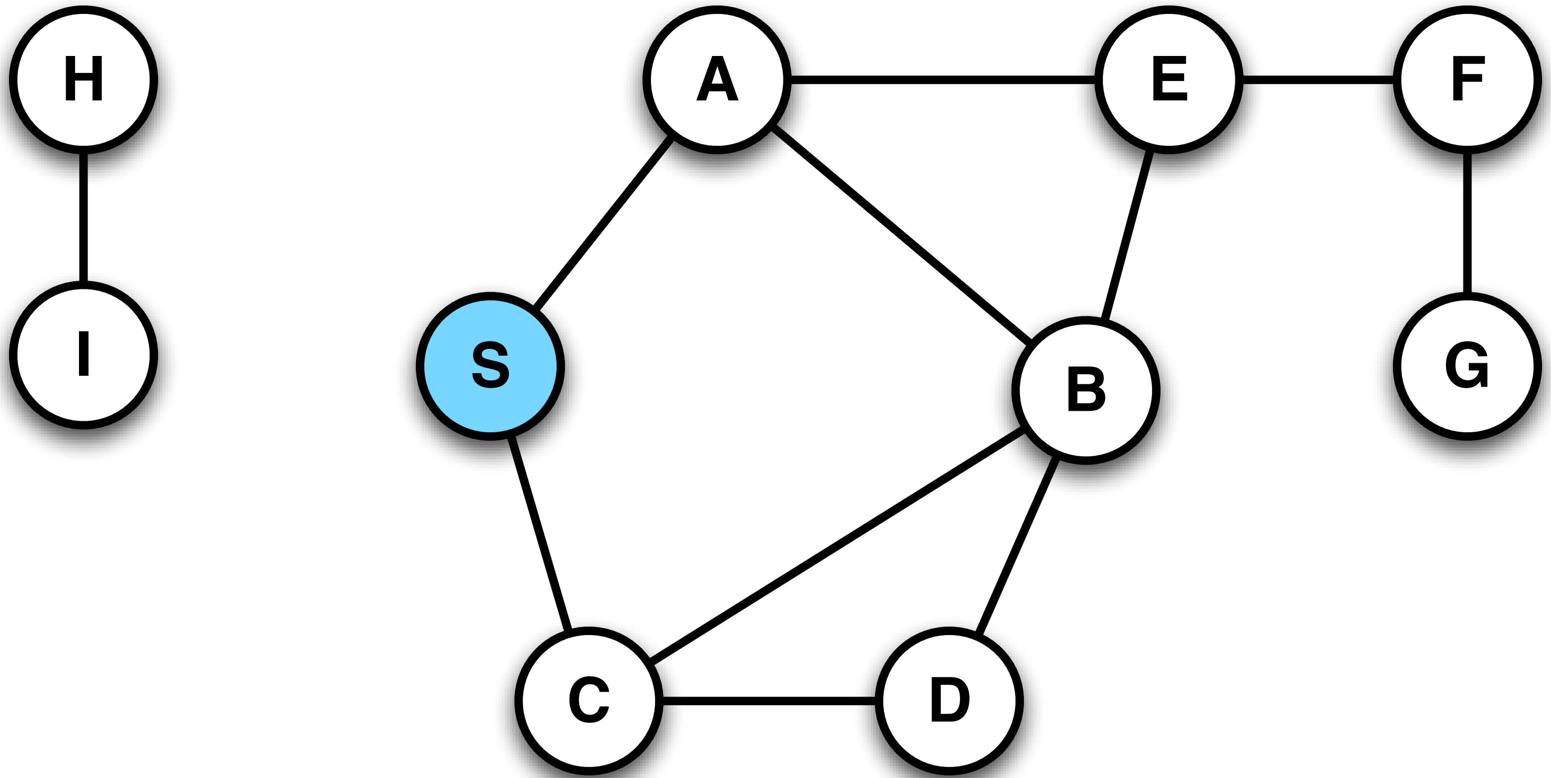
AODV

- **Perkins, Royer**
  - Ad hoc On-Demand Distance Vector Routing, IEEE Workshop on Mobile Computing Systems and Applications,1999
- ~~**Reaktives Routing-Protokoll**~~
- **Reactive routing protocol**
  - Improvement of DSR D
  - no source routing
  - Distance Vector Tables
    - but only for nodes with demand
  - Sequence number to help identify outdated cache info
  - Nodes know the origin of a packet and update the routing table

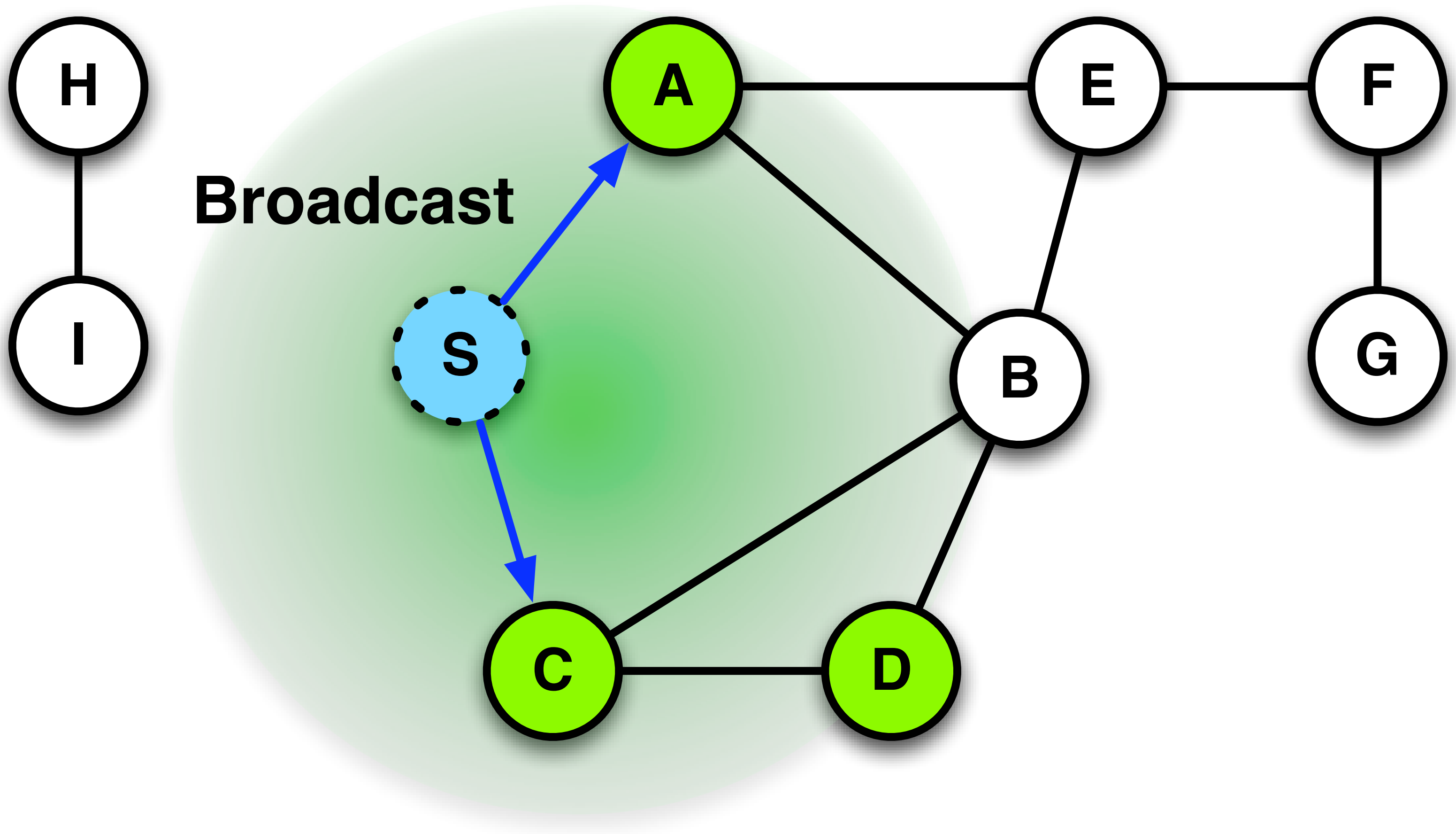
AODV

- **Algorithm**
  - Route Request (RREQ) like in DSR
  - Intermediate nodes set a reverse pointer towards thesender
  - If the target is reached, a Route Reply (RREP) is sent
  - Route Reply follow the pointers
- **Assumption: symmetric connections**

AODV: Example

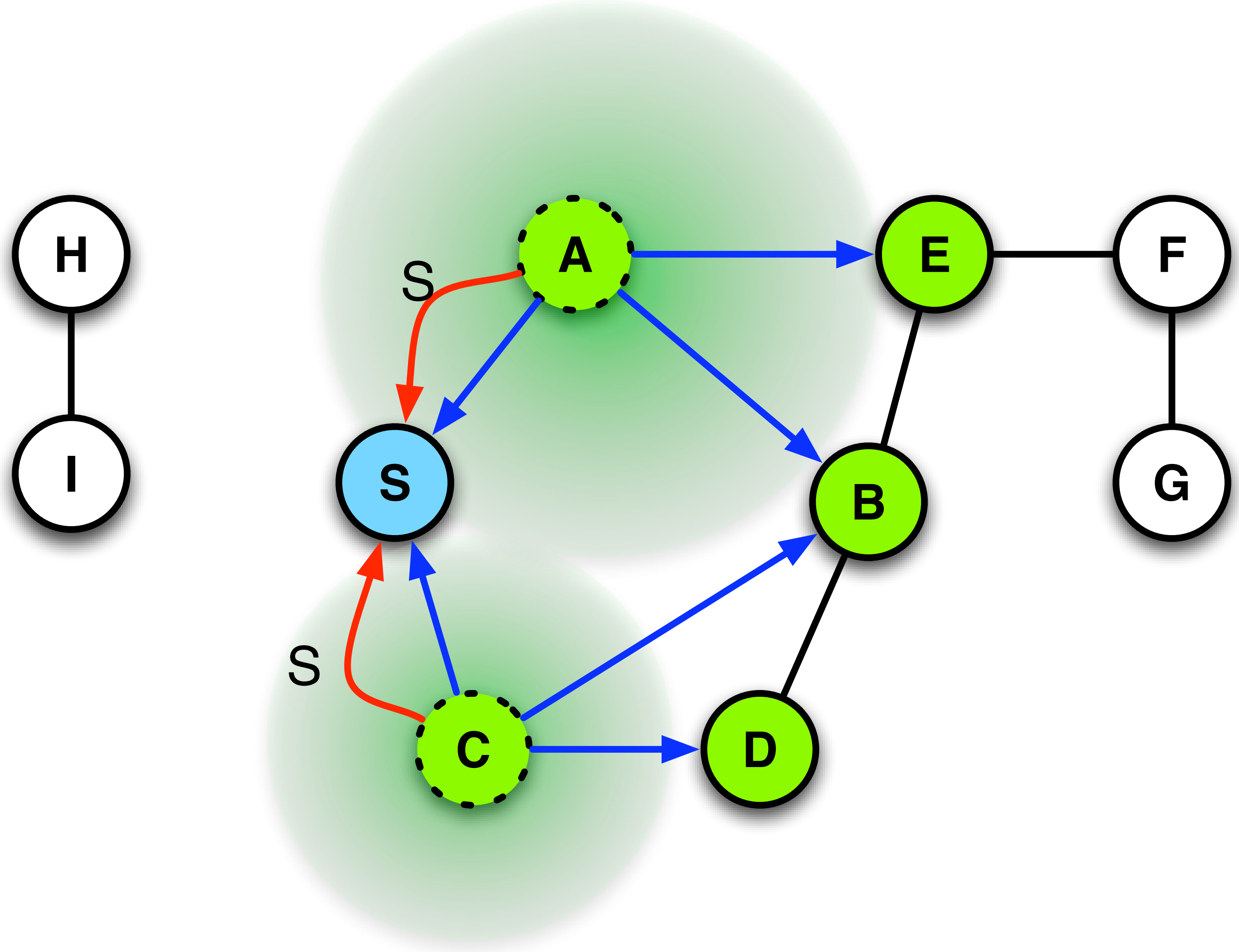


AODV: Example

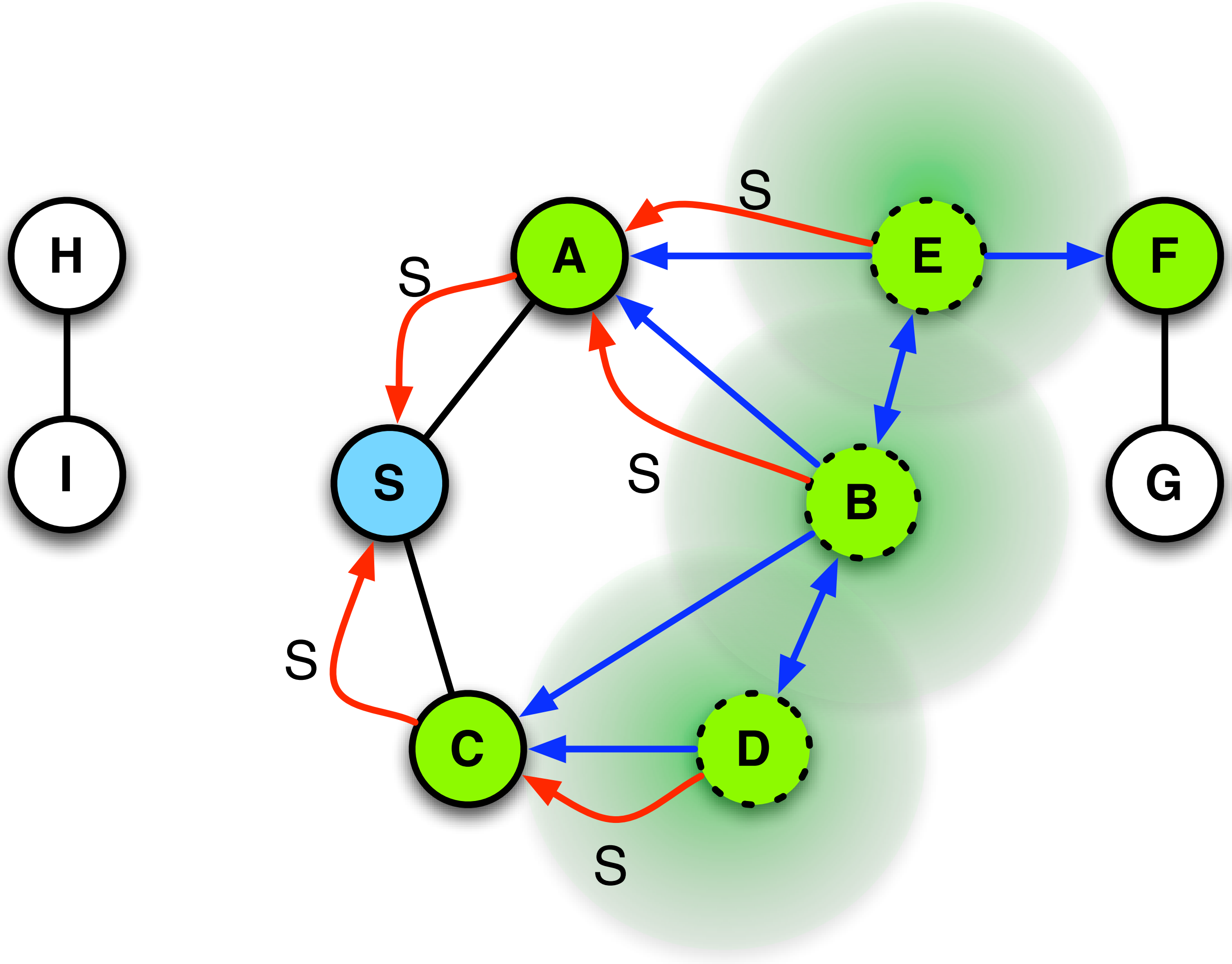


AODV: Example

A	via
	A
S	A
?	–
?	–

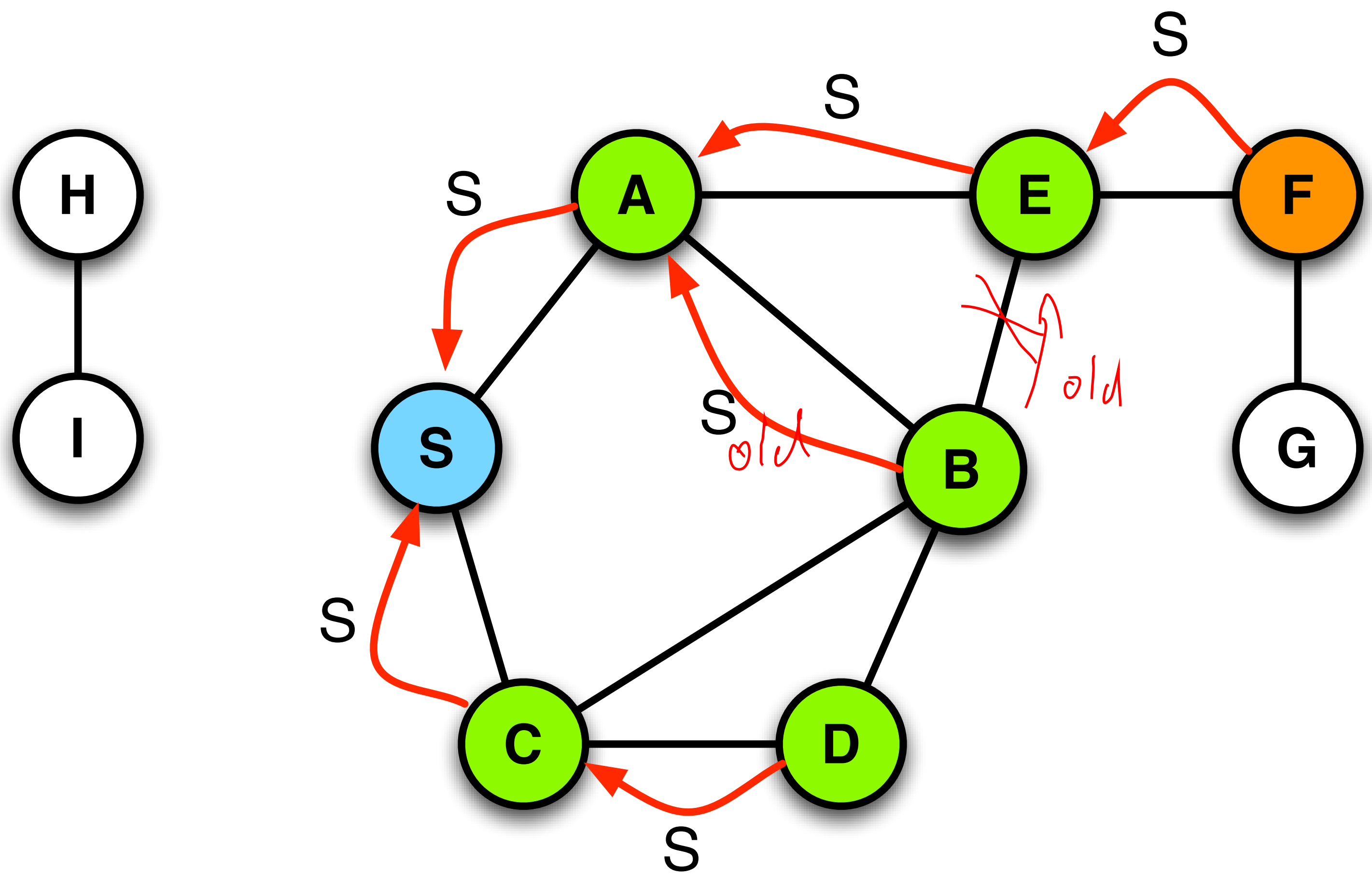


AODV: Example

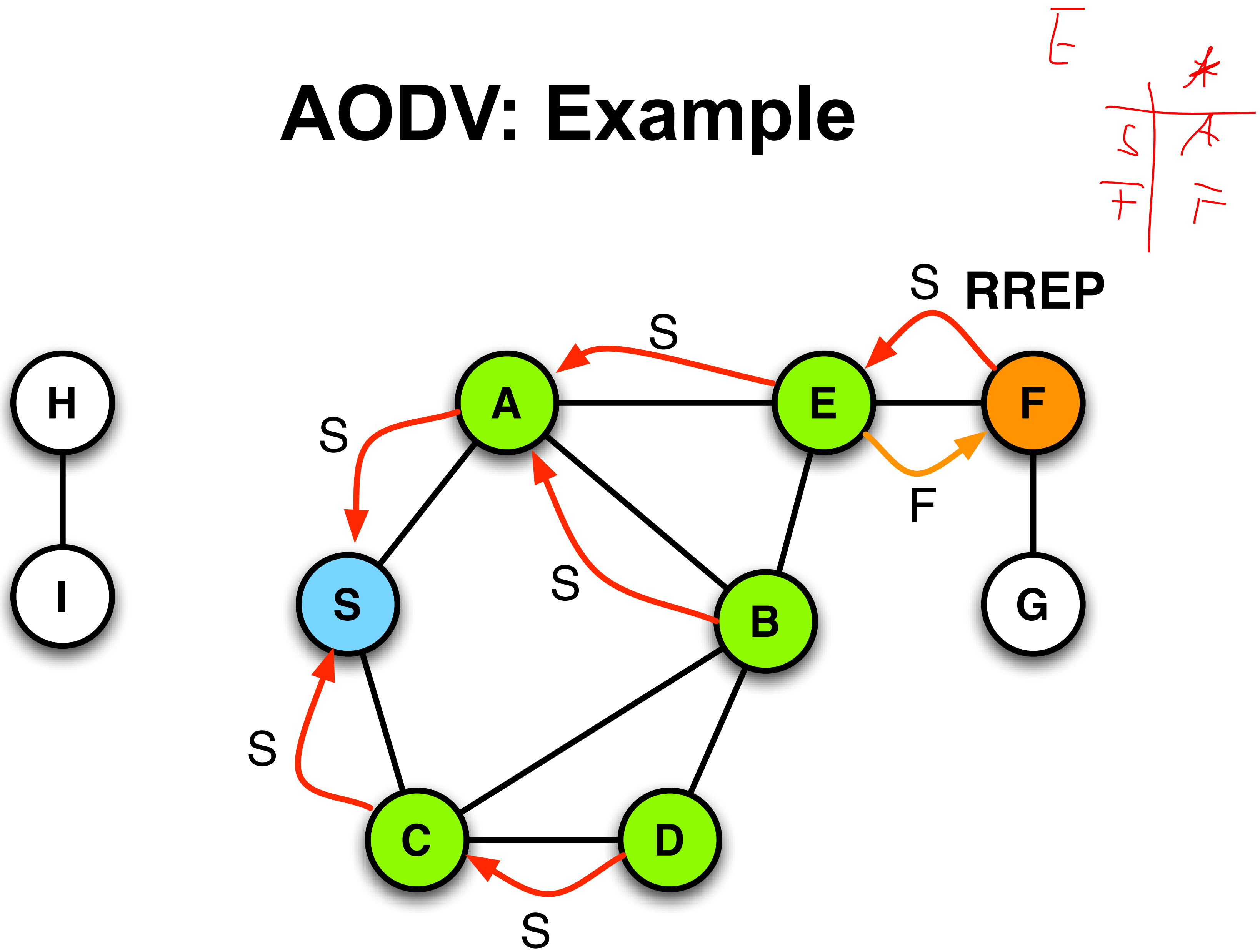


AODV: Example

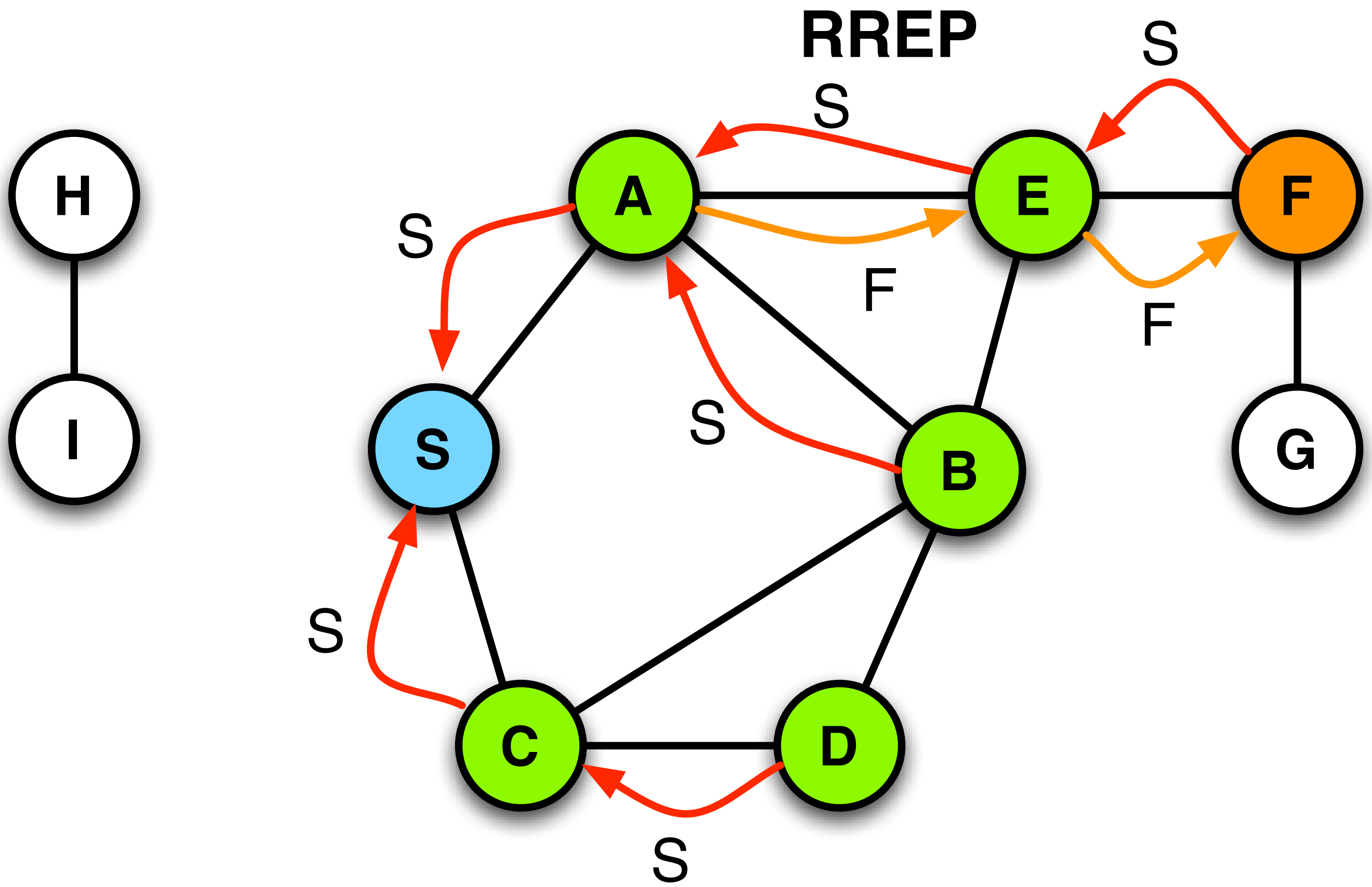
F | via
S | E



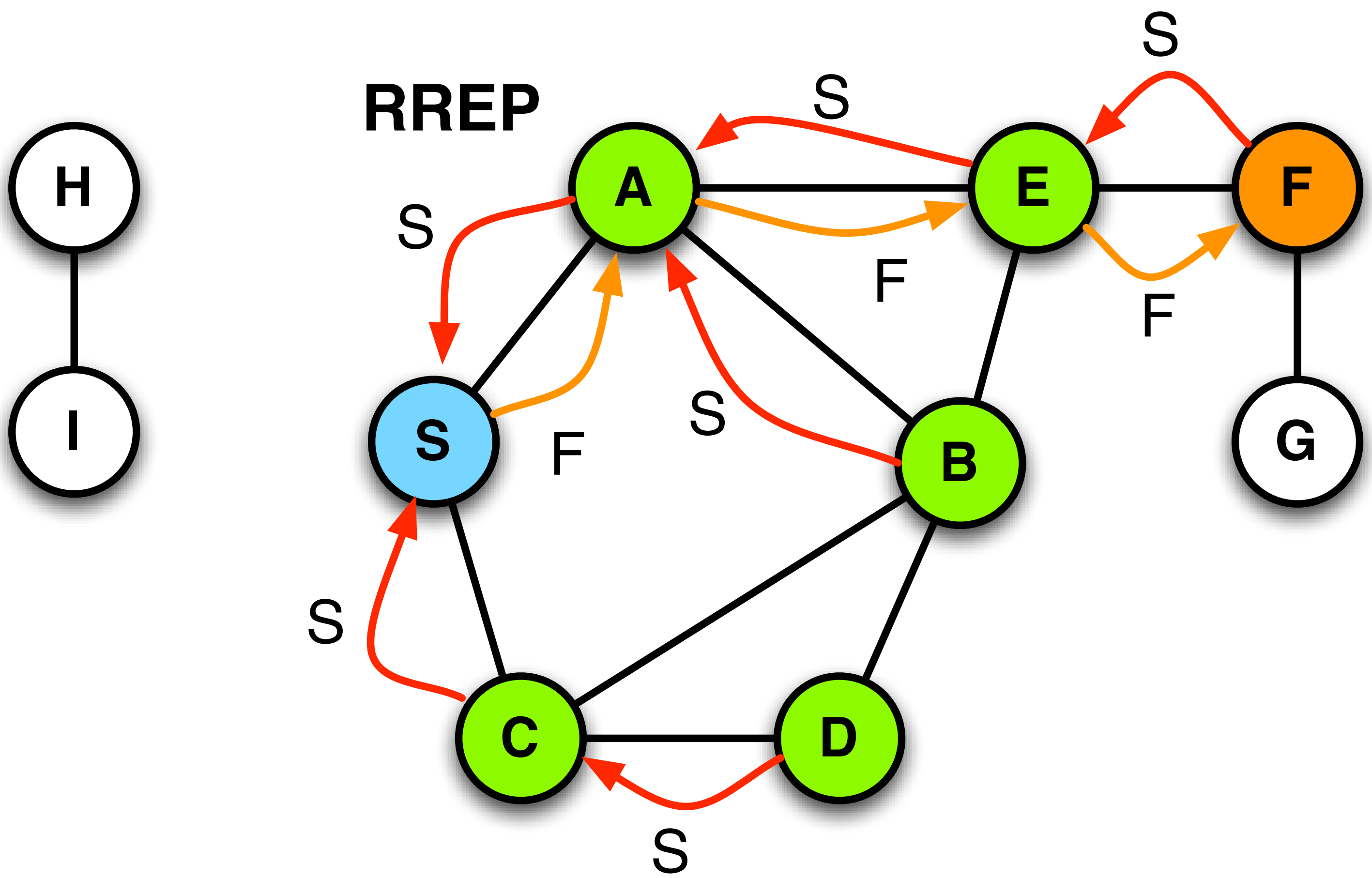
AODV: Example



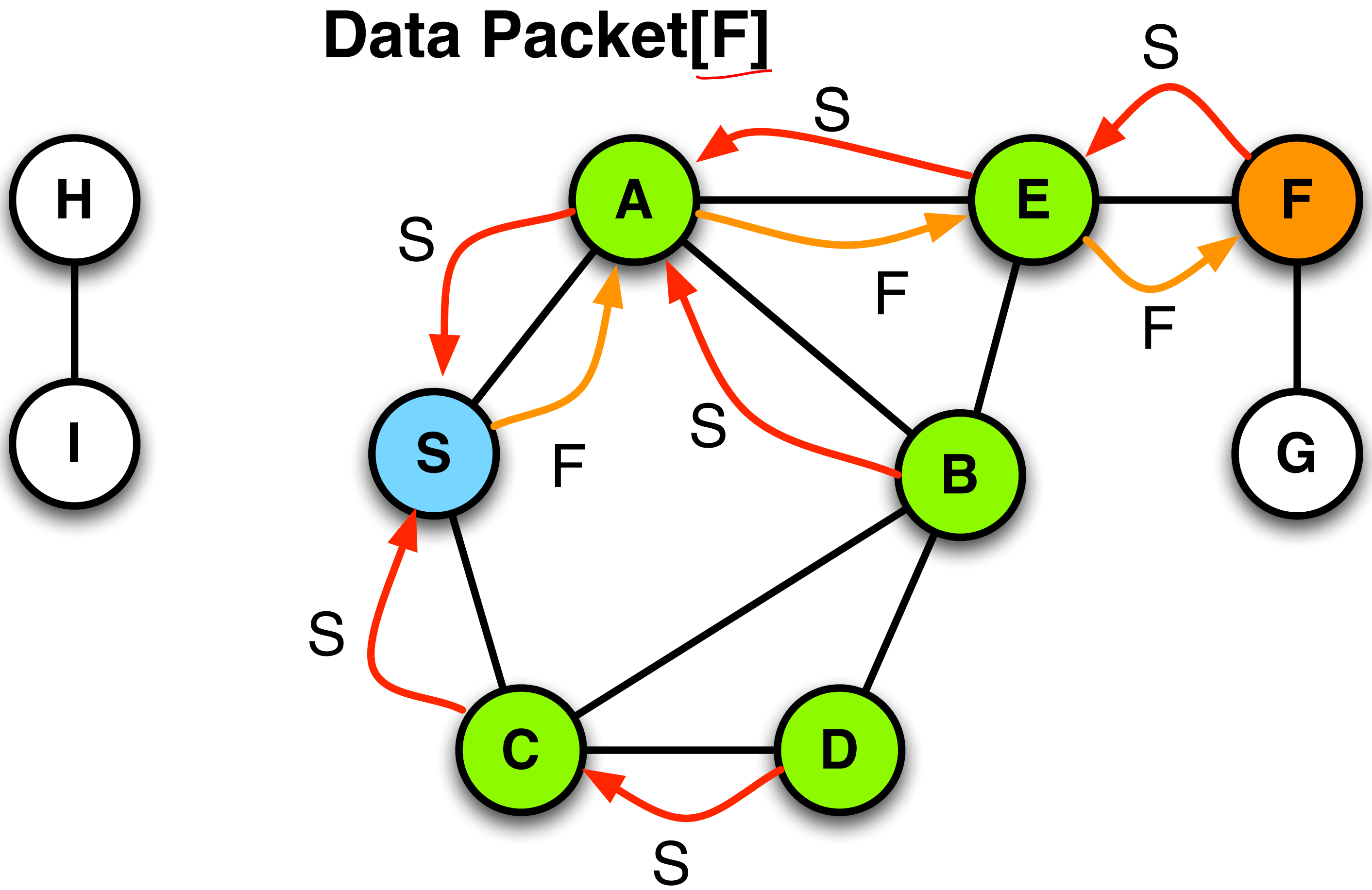
AODV: Example



AODV: Example



AODV: Example



Route Reply in AODV

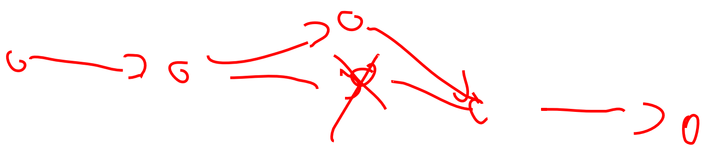
- **Intermediate nodes**
  - may send route-reply packets, if their cache information is up-to-date
- **Destination Sequence Numbers**
  - measure the up-to-dateness of the route information
  - AODV uses cached information less frequently than DSR
  - A new route request generates a greater destination sequence number
  - Intermediate nodes with a smaller sequence number may not generate a route reply (RREP) packets

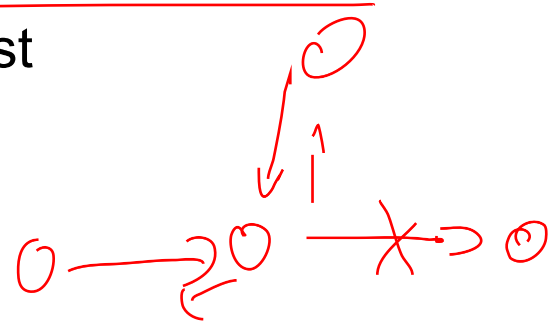
Timeouts

- **Reverse pointers are deleted after a certain time**
  - RREP timeout allows the transmitter to go back
- **Routing table information to be deleted**
  - if they have not been used for some time
  - Then a new RREQ is triggered

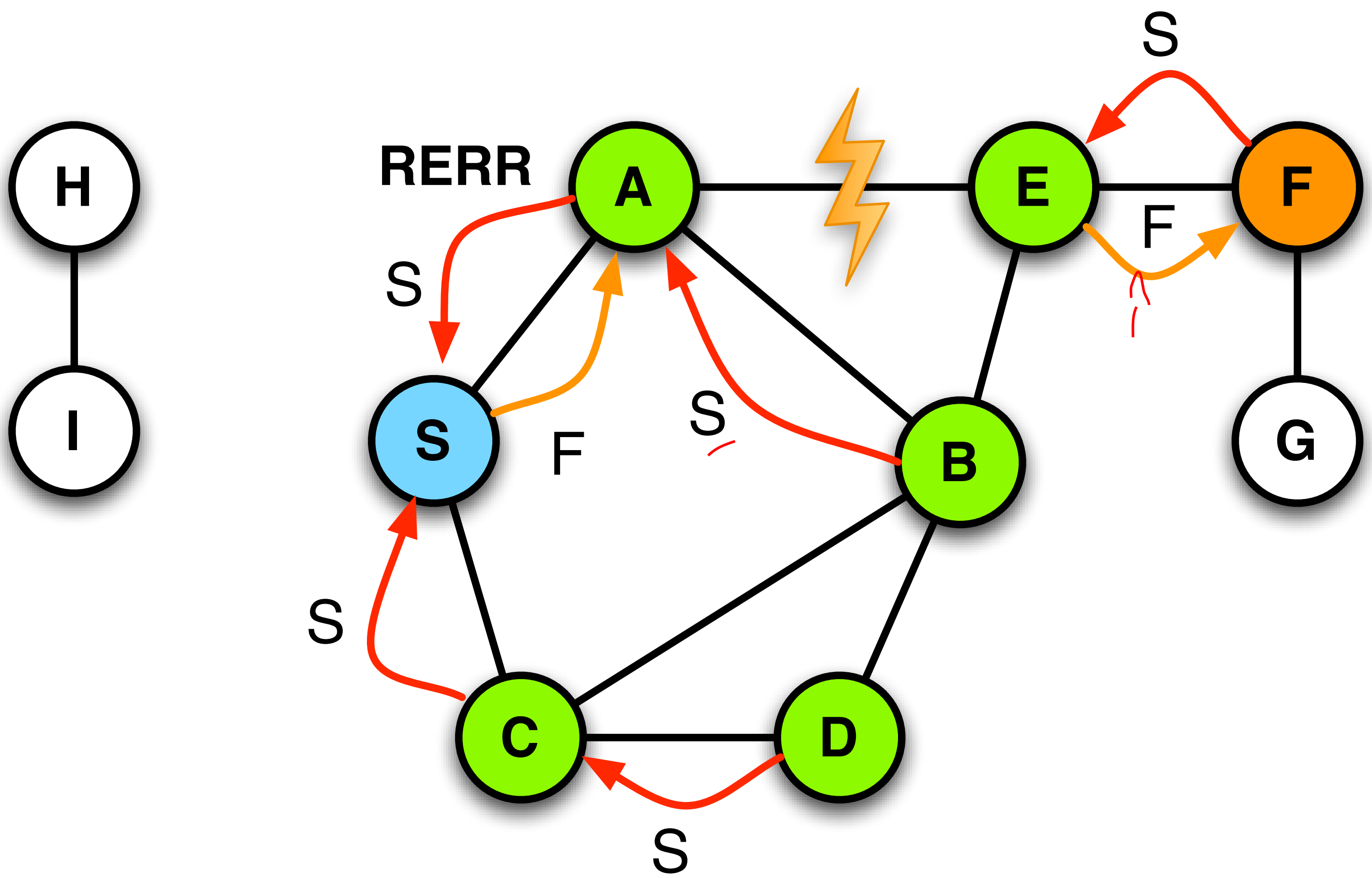
Link Failure Reporting

- **Neighbors of a node X are active,**
  - if the routing table cache are not deleted
- **If a link of the routing table is interrupted,**
  - then all active neighbors are informed
- **Link failures are distributed by Route Error (RERR) packets to the sender**
  - also update the Destination Sequence Numbers
  - This creates new route request





AODV: Example



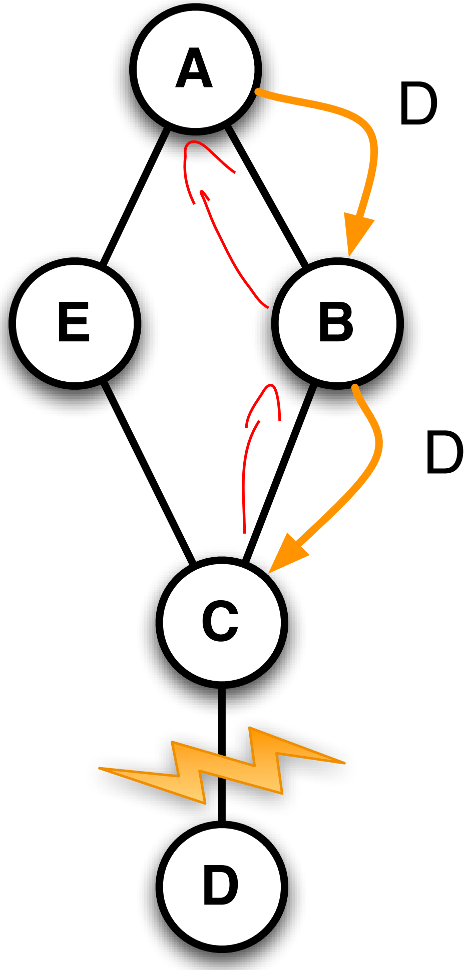
Detection of Link Failure

$\longleftrightarrow$ proactive

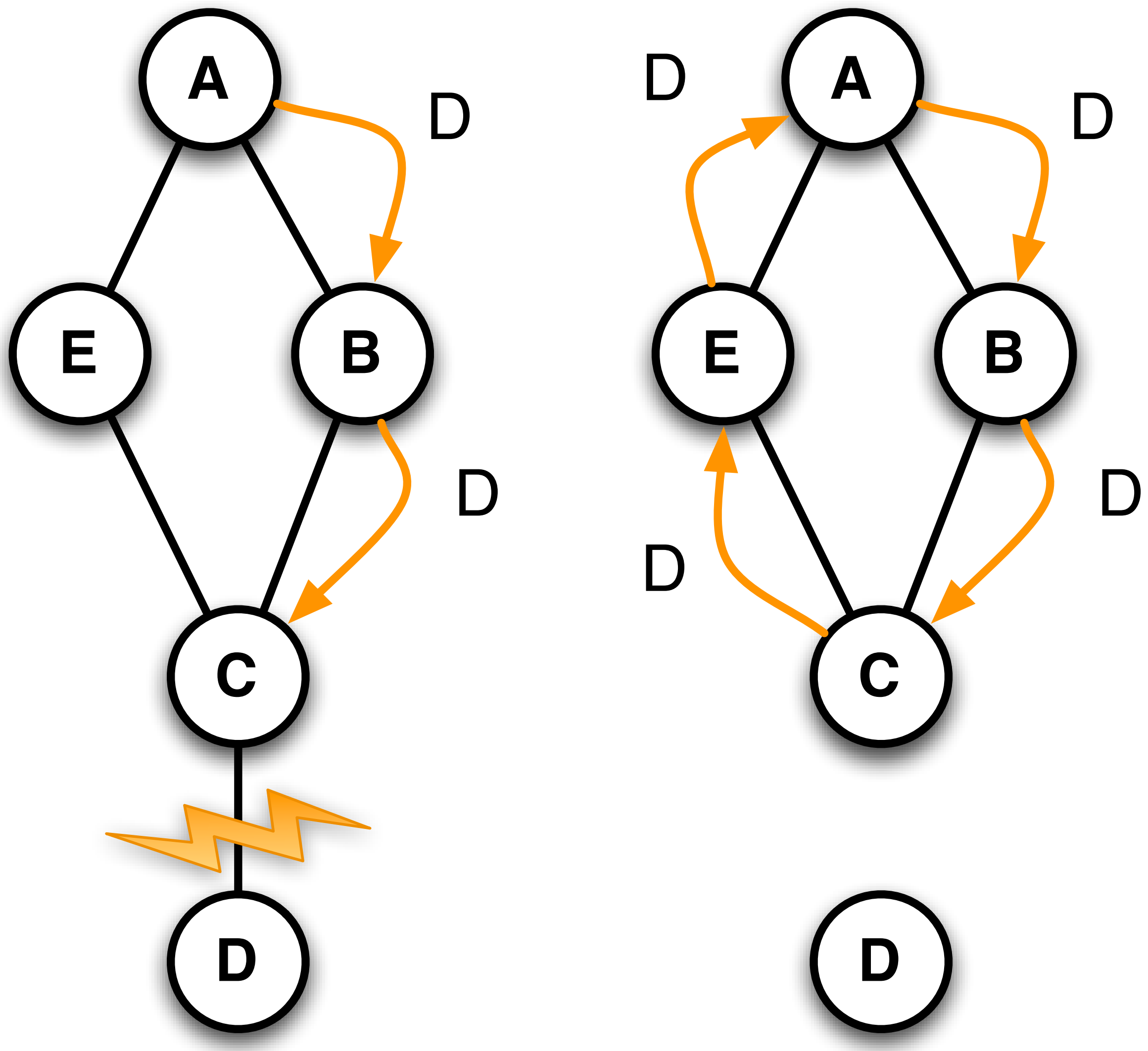
- **Hello messages**
  - neighboring nodes periodically exchange hello packets from
  - Absence of this message indicates link failure
- **Alternative**
  - use information from MAC protocol

Sequence Numbers

- **When a node receives a message with destination sequence number N**
  - then this node sets its number to N
  - if it was smaller before
- **In order to prevent loops**
  - If A has not noticed the loss of link (C, D)
    - (for example, RERR is lost)
  - If C sends a RREQ
    - on path C-E-A
  - Without sequence numbers, a loop will be constructed
    - since A "knows" a path to D, this results in a loop (for instance, CEABC)



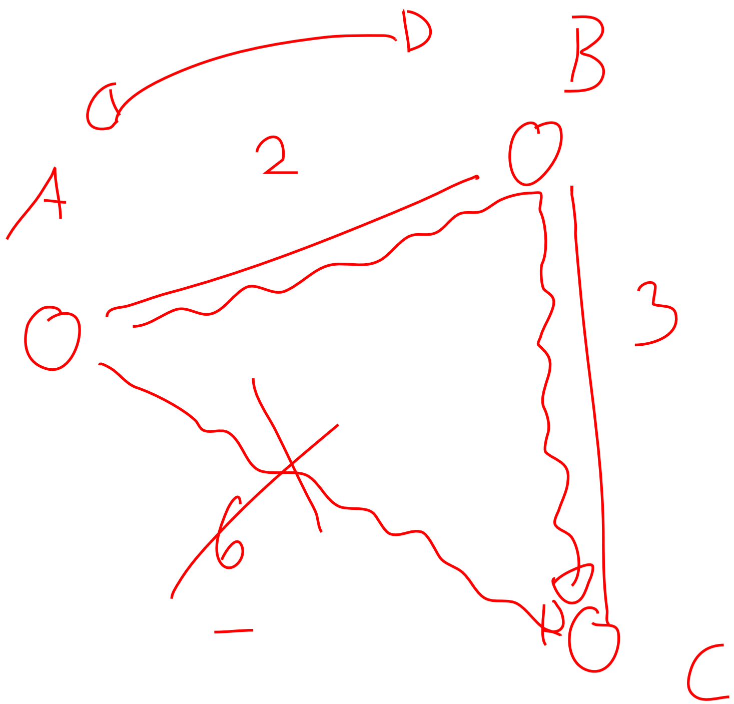
Sequence Numbers

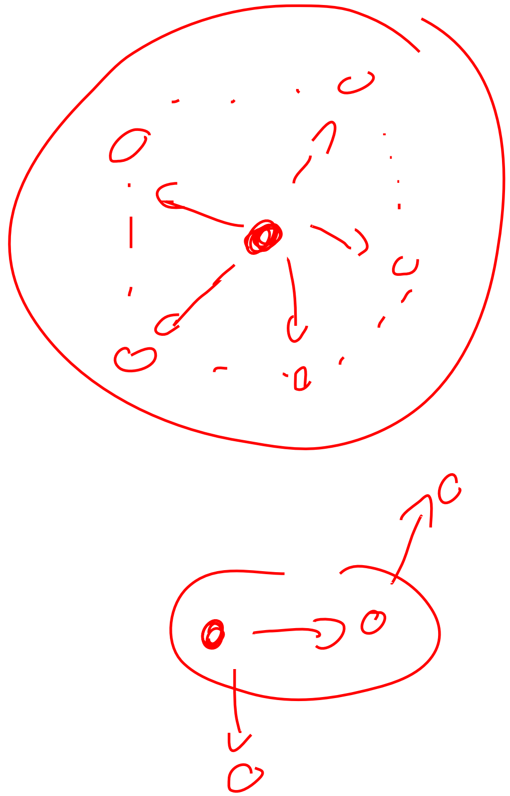


Optimization
Expanding Ring Search

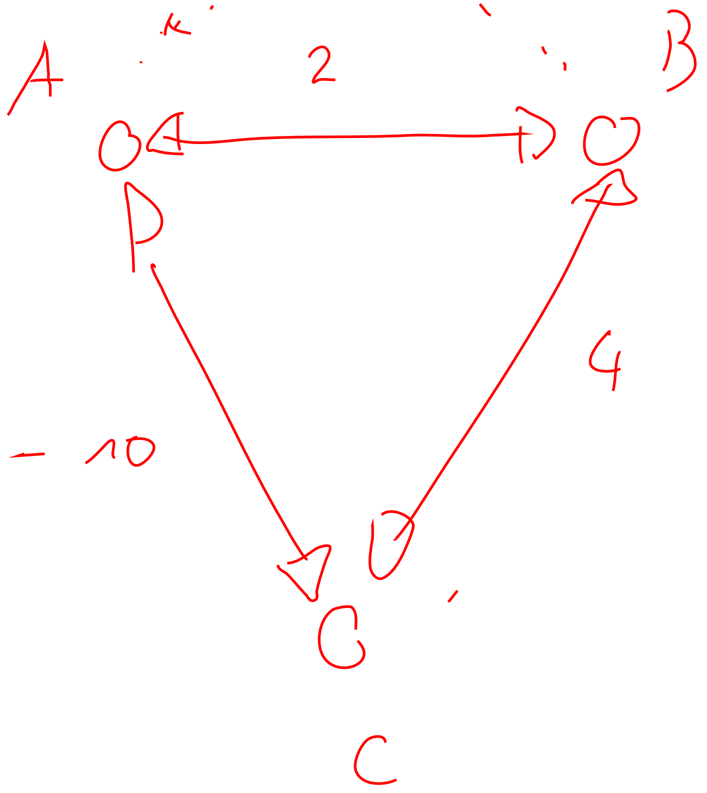
- **Route Requests**
  - *start with small time-to-live value (TTL)*
  - if no Route Reply (RREP) is received, the value is increased by a constant factor and resent
- **This optimization is also applicable for DSR**

Relax





Bellman Ford



A → C -10

A → B 2

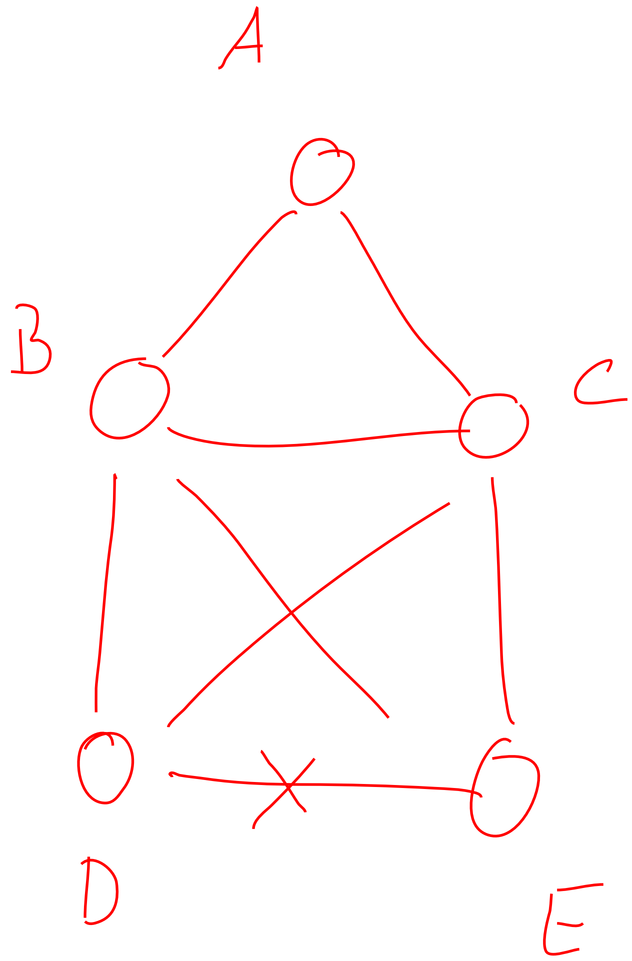
B → A : ~~A~~ -8

B → C : ~~X~~ -6

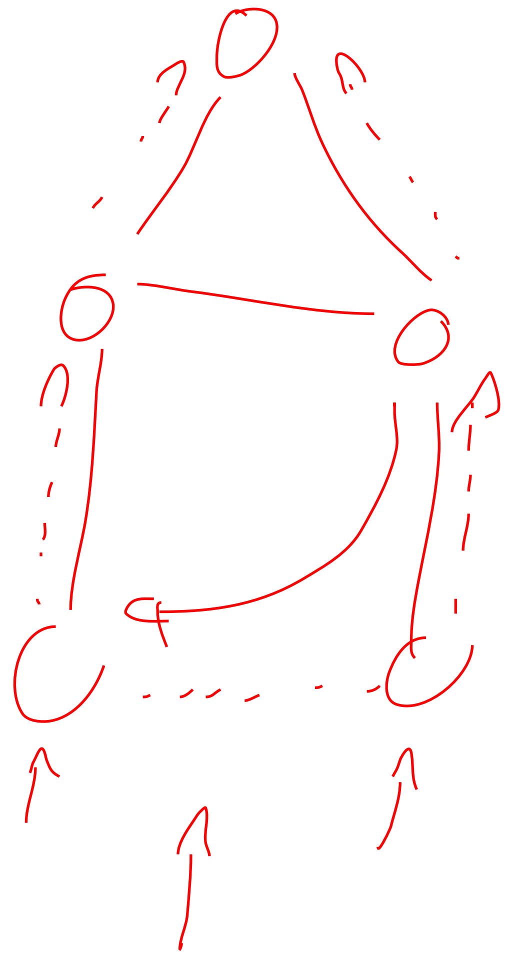
C → A : -10

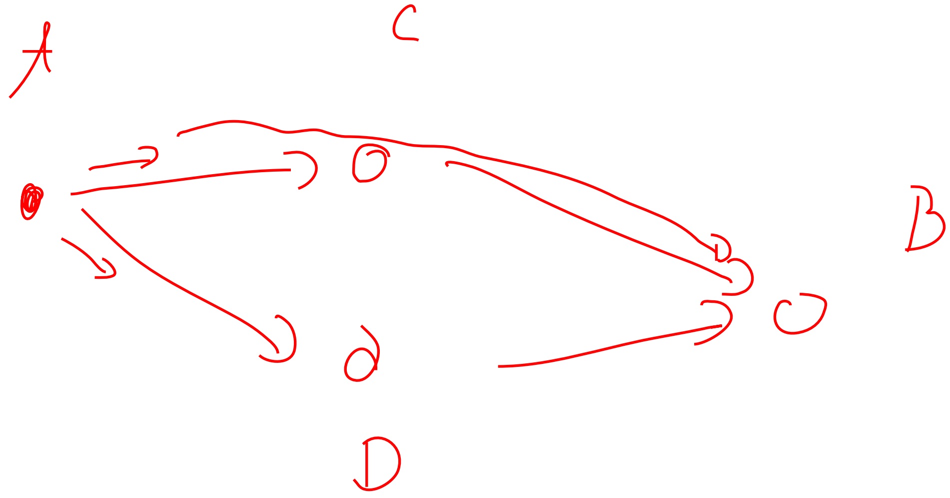
C → B : ~~4~~ -4

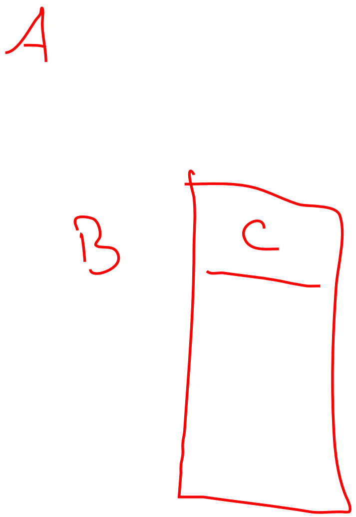
negative cost cycle



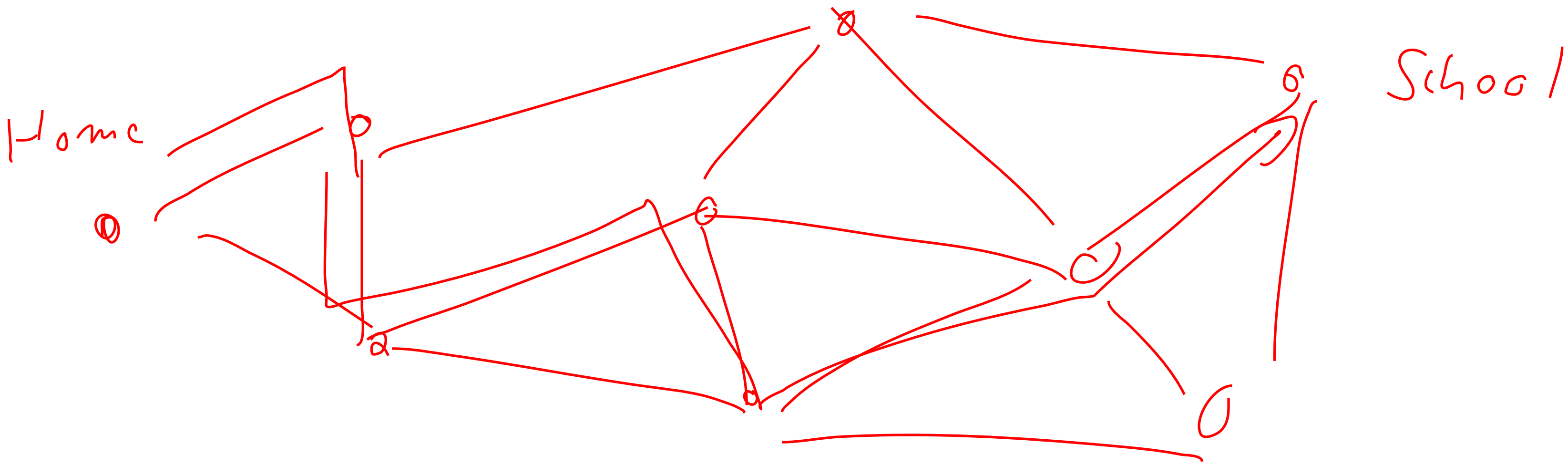
A
B
C
D
E

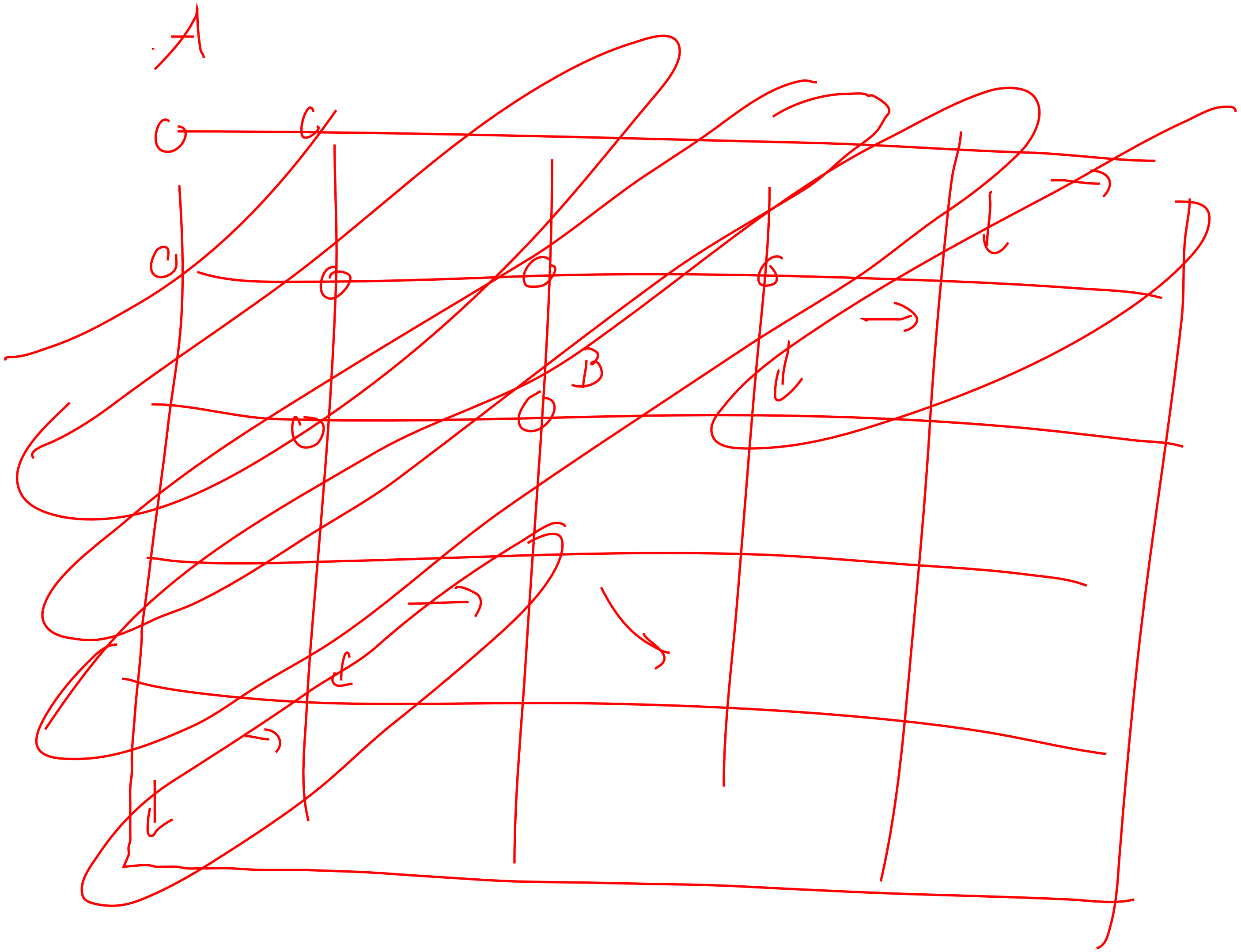


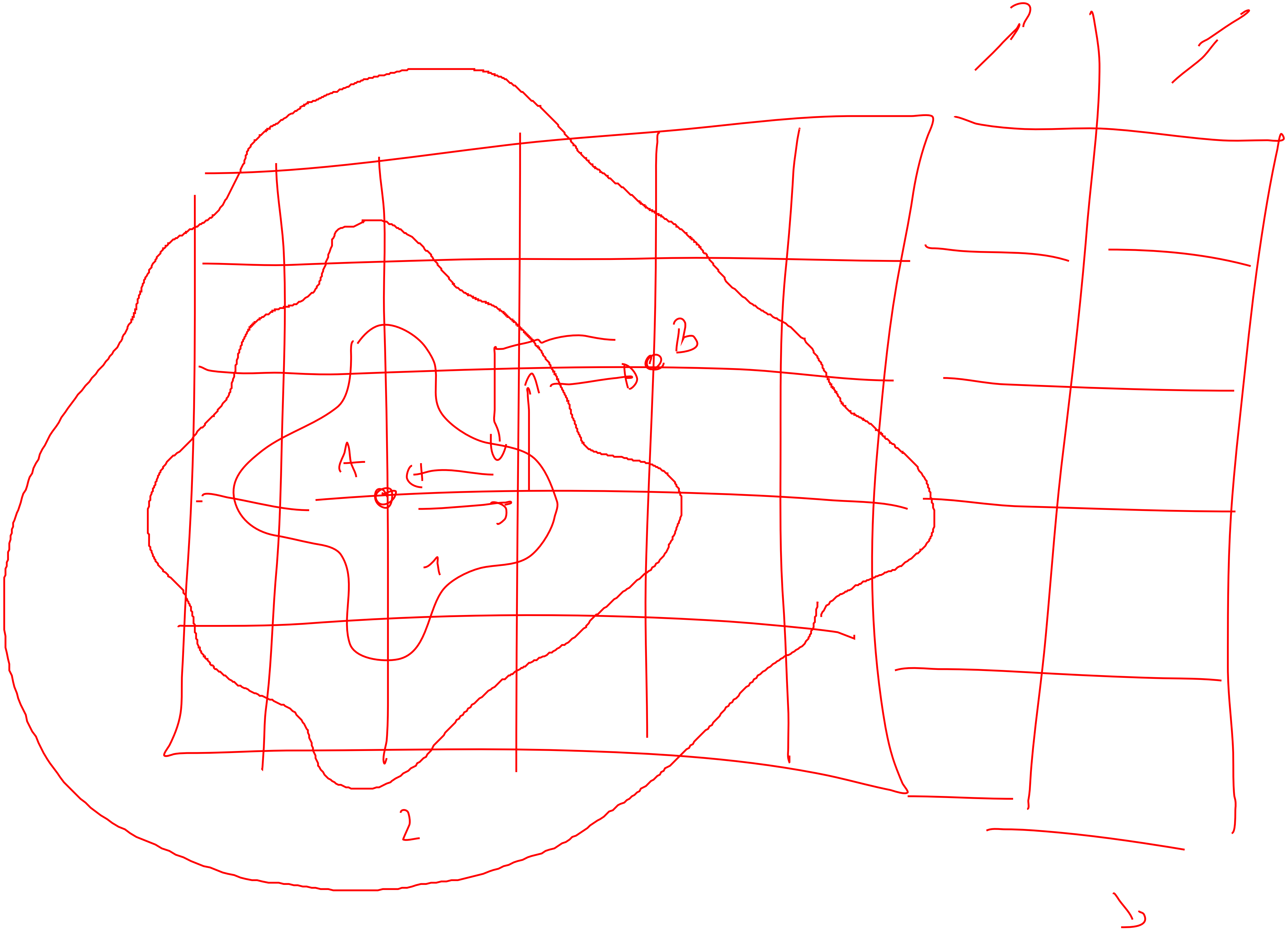

A
C
B
D

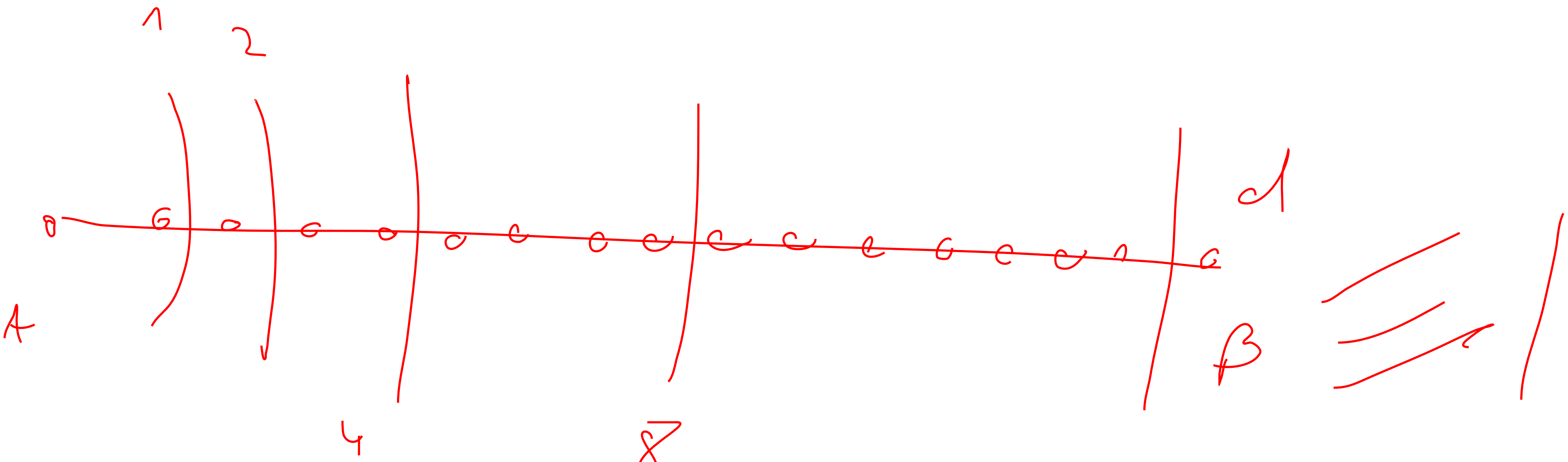

A
B
C

SOURCE ROUTING




A
B





$1+1$

$2+2$

$4+4$

$8+8$

$16+16$

$32+32$

$\lceil \log d \rceil$

$$\sum_{i=1}^{i} 2^i \cdot 2 = 2 \cdot 2^{\log d + 1}$$

$$= 2 \cdot 2 \cdot 2^{\log d}$$

$$= 4 \cdot d$$